THE MANUFACTURE
OF
PULP AND PAPER

VOLUME V

Pulp and Paper Manufacture

IN FIVE VOLUMES

An Official Work Prepared
under the direction of the

Joint Textbook Committee of the
Paper Industry of the United States and
Canada

VOL. I—MATHEMATICS, HOW TO READ DRAWINGS, PHYSICS.
II—MECHANICS AND HYDRAULICS, ELECTRICITY, CHEMISTRY.
III—MANUFACTURE OF PULP.
IV, V—MANUFACTURE OF PAPER.

THE

MANUFACTURE

OF

PULP AND PAPER

A TEXTBOOK OF MODERN PULP AND PAPER MILL PRACTICE

Prepared Under the Direction of the Joint Textbook Committee of the Paper Industry of the United States and Canada

VOLUME V

PAPERMAKING MACHINES; HANDMADE PAPERS; PAPER FINISHING; COATED PAPERS; PAPER TESTING; PAPERMAKING DETAILS

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THIRD EDITION

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PREFACE TO THE THIRD EDITION

Of the five volumes composing this textbook, the first two volumes cover the subjects of mathematics and general science to a degree that affords the student a practical understanding of the technology of the manufacturing processes covered in Volumes III, IV, and V. The third edition of Volume III, which deals with the manufacture, treatment, bleaching, and testing of pulp, was issued in February, 1937. Volumes IV and V constitute a treatise on the manufacture of paper. The third edition of Volume IV, which was published in February, 1938, includes, among other subjects, the pulping of rags and other fibers, processing waste papers, beating and refining, fillers, sizing, coloring, auxiliary mill equipment, heating and ventilation. The many changes which were found necessary in the revision of these two volumes indicate the great advances that have been made in the paper industry during the past ten years.

In the third edition of Volume V special attention is directed to the following features: The section on papermaking machines embodies descriptions of new headbox designs, a new method of installing the wire, a new press part, a new electric drive, an additional chapter on insulating boards, and new designs of cylinder machines. Extensive changes have been made in the text on handmade papers (now a section by itself) and in papermaking details. The sections on coated papers and paper testing have been rewritten.

Grateful acknowledgment is hereby extended to the many friends who, by their kind encouragement, helpful criticism, and practical suggestions, have been of great assistance in the preparation of this revision. Any further suggestions for improvement of the texts will be welcomed.

J. N. STEPHENSON,
Editor.

GARDENVALE, QUEBEC,
January, 1939.

EXTRACTS FROM THE PREFACE TO THE FIRST EDITION

In numerous communities where night schools and extension classes have been started or planned, or where men wished to study privately, there has been difficulty in finding suitable textbooks. No books were available in English which brought together the fundamental subjects of mathematics and elementary science and the principles and practice of pulp and paper manufacture. Books that treated of the processes employed in this industry were too technical, too general, out of date, or so descriptive of European machinery and practice as to be unsuitable for use on this Continent. Furthermore, a textbook was required that would supply the need of the man who must study at home because he could not or would not attend classes.

After considerable study of the situation by the Committee on Education for the Technical Section of the Canadian Pulp and Paper Association and the Committee on Vocational Education for the Technical Association of the (U. S.) Pulp and Paper Industry, a joint meeting of these committees was held in Buffalo in September, 1918, and a Joint Executive Committee was appointed to proceed with plans for the preparation of the text, its publication, and the distribution of the books. The scope of the work was defined at this meeting, when it was decided to provide for preliminary instruction in fundamental mathematics and elementary science, as well as in the manufacturing operations involved in modern pulp and paper mill practice.

The Joint Executive Committee then chose an Editor, Associate Editor, and Editorial Advisor, and directed the Editor to organize a staff of authors consisting of the best available men in their particular lines, each to contribute a Section dealing with his specialty. A general outline, with an estimated budget, was presented at the annual meetings in January and February, 1919, of the Canadian Pulp and Paper Association, the Technical

Association of the Pulp and Paper Industry, and the American Paper and Pulp Association. It received the unanimous approval and hearty support of all, and the budget asked was raised by an appropriation of the Canadian Pulp and Paper Association and contributions from paper and pulp manufacturers and allied industries in the United States, through the efforts of the Technical Association of the Pulp and Paper Industry.

To prepare and publish such a work is a large undertaking: its successful accomplishment is unique, as evidenced by these volumes, in that it represents the cooperative effort of the Pulp and Paper Industry of a whole Continent.

Volume III is the first book published in English that deals solely and comprehensively with the manufacture of wood pulp. The attention here given to this subject is warranted by the essential place now held by this source of papermaking material. From a practically unknown factor fifty years ago, the making of pulp is now a major industry, employing thousands of workmen, and converting much wood, otherwise worthless, into an important article of international commerce. The greatest advances in connection with the paper industry have been in the development of pulp manufacture. Even this volume is too small to tell the whole story, the study of which will fascinate and benefit anyone connected with this industry.

A feature of this series of volumes is the wealth of illustrations, which are accompanied by detailed descriptions of typical apparatus. In order to bring out a basic principle, it has been necessary, in some cases, slightly to alter the maker's drawing, and exact scales have not been adhered to. Since the textbook is in no sense a "machinery catalog," makers' names have been mentioned only when they form a necessary descriptive item. Much of the apparatus illustrated and many of the processes described are covered by patents, and warning is hereby given that patent infringements are costly and troublesome.

A valuable feature of this work, which distinguishes it from all others in this field, is that each Section was examined and criticized while in manuscript by several competent authorities; in fact, this textbook is really the work of more than one hundred men who are prominent in the pulp and paper industry. Without their generous assistance, often at personal sacrifice, the work could not have been accomplished. Even as it stands,

there are, no doubt, features that still could be improved. The Committee, therefore, welcomes helpful criticisms and suggestions that will assist in making future editions of still greater service to all who are interested in the pulp and paper industry.

The Editor extends his sincere thanks to the Committee and others, who have been a constant support and a source of inspiration and encouragement; he desires especially to mention Mr. George Carruthers, Chairman, and Mr. R. S. Kellogg, Secretary, of the Joint Executive Committee; Mr. J. J. Clark, Associate Editor, and Mr. T. J. Foster, Editorial Advisor.

The Committee and the Editor have been generously assisted on every hand; busy men have written and reviewed manuscript, and equipment firms have contributed drawings of great value and have freely given helpful service and advice. Among these kind and generous friends of the enterprise are: Mr. M. J. Argy, Mr. O. Bache-Wiig, Mr. James Beveridge, Mr. J. Brooks Beveridge, Mr. H. P. Carruth, Mr. Martin L. Griffin, Mr. H. R. Harrigan, Mr. Kenneth T. King, Mr. Maurice Neilson, Mr. Elis Olsson, Mr. J. S. Riddile, Mr. George K. Spence, Mr. Edwin Sutermeister, Mr. F. G. Wheeler, and Bird Machine Co., Canadian Ingersoll-Rand Co., Claflin Engineering Co., Dominion Engineering Works, E. I. duPont de Nemours Co., General Electric Co., Harland Engineering Co., F. C. Huyck & Sons, Hydraulic Machinery Co., Improved Paper Machinery Co., E. D. Jones & Sons Co., A. D. Little, Inc., E. Lungwitz, National Aniline and Chemical Works, Paper Makers' Chemical Co., Process Engineers, Pusey & Jones Co., Rice, Barton & Fales Machine and Iron Works, Ticonderoga Paper Co., Waterous Company, Ltd., Westinghouse Electric & Manufacturing Co., and many others, particularly the authors of the various sections, who have devoted so much time and energy to the preparation of manuscript, often at personal sacrifice.

J. NEWELL STEPHENSON,
Editor.

FOR THE
JOINT TEXTBOOK COMMITTEE OF THE PAPER INDUSTRY,
GEORGE CARRUTHERS, *Chairman*, R. S. KELLOGG, *Secretary*
T. L. CROSSLEY, G. E. WILLIAMSON, R. S. HATCH.

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SECTION 1

PAPERMAKING MACHINES

(PART 1)

By J. W. BRASSINGTON
Revised by GEORGE D. BEARCE

THE PAPERMAKING MACHINE AND ITS EQUIPMENT

GENERAL DESCRIPTION

1. Introduction.—Two standard types of paper machines are used to manufacture the many and varied grades of paper: (1) the Fourdrinier machine; (2) the cylinder machine. In addition, there are a number of special types of paper machines that are a combination of these two types, or that are equipped with special attachments for some particular operation.

The general method of making paper is essentially the same for all types of machines. The web of paper is first formed on the traveling wire in the case of the Fourdrinier, or on the cylinder mold of the cylinder machine. This wet sheet is further dewatered by the press section of the machine, dried out by the dryers, and finished or smoothed out by the calenders.

The Fourdrinier paper machine, its operation, and its equipment will be discussed in Parts 1–5 of this Section, and this will be followed by the cylinder and other special paper machines. While the principles of making paper on the various types of machines are similar, the details of forming the sheets, pressing, drying, and calendering are not the same, and they require separate treatment to get an adequate conception of the operating methods of each type of paper machine.

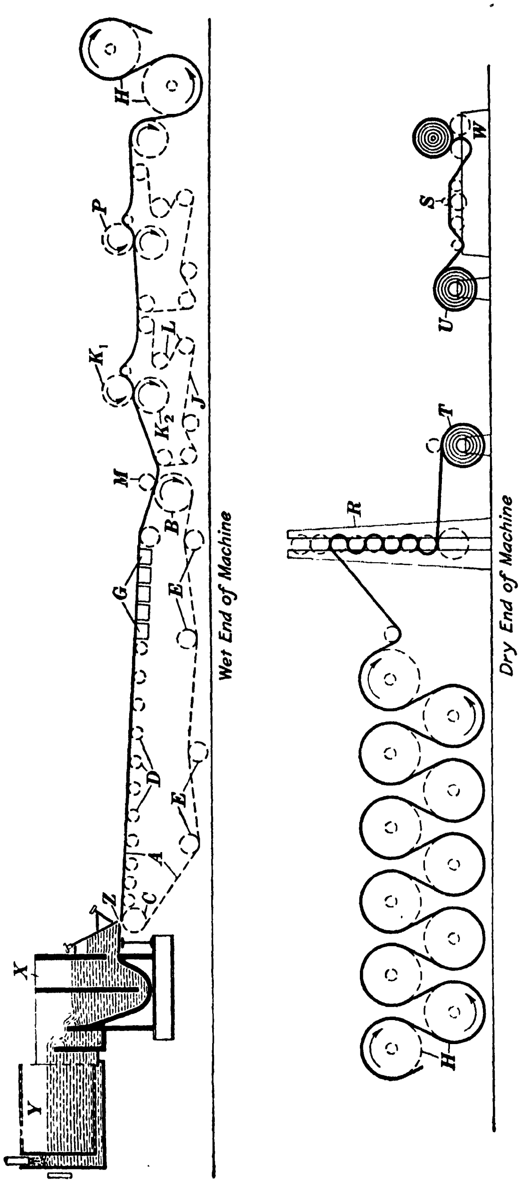

Wet End of Machine
Dry End of Machine
X
Y
Z
C
A
D
E
E
G
B
M
K2
J
K1
L
P
H
R
T
U
S
W
H

FIG. 1.

2. Fourdrinier Paper Machine.—The principal parts of the modern Fourdrinier machine are shown diagrammatically in Fig. 1. The course of the paper through the machine is also indicated.

The *stock*, which is about $\frac{1}{2}$% fiber, depending on the grade of paper being made, is first sent through the screens *Y* by gravity. It then goes through the *flow-box*, or *headbox*, *X*, from which it is forced by its own weight out through the *slice Z* onto the endless wire screen *A*. This *wire* is driven by the *couch roll B*, supported by the *breast roll C*, the *table rolls D*, and *wire rolls E*. Much water drains through the wire at the table rolls, more is taken out by the flat *suction boxes G*, and the *suction couch roll B*. Many modern machines are equipped with a rubber *rider roll M*, which replaces the *top couch roll*. The older paper machines, and some making special papers, use a plain bottom couch roll with a jacketed top couch roll, the combination forming a *couch press* that squeezes water from the sheet. From the wire, the sheet is transferred to the *first press felt J*, which is an endless woolen blanket, and passes between the top and bottom rolls K_1 and K_2, where more water is removed and the sheet further pressed. Most modern machines use a perforated bottom suction-press roll to facilitate the removal of water from the sheet. The felt *J* is supported and kept tight by the *felt* and *stretch rolls L*. The next step is to transfer the sheet to the *second press P*, which is similar to the first press, and then to the *third press*, in case the machine is so equipped. Many machines use a *reverse* last press, although a *straight-through* press, as here shown, is satisfactory for many grades of paper. After the paper leaves the press part, it is about 60 to 70 per cent water, and it then goes over the steam-heated *dryers H*, which evaporate additional water and make it 90 to 94 per cent dry. In its passage through the dryer part (unless very thick and strong), the paper is carried and kept in contact with the dryers by canvas felts. The dried sheet then goes through the *calender stack R*, which consists of a series of smooth, heavy rolls, and the paper is *calendered*, *i.e.*, given a smooth surface. The sheet is now wound on the *reel T* as rapidly as formed on the machine. When one of the reels is full, the sheet is transferred to an empty reel, and the full reel is transferred to the reel stand *U*, from which it is run through the *slitters S* of the *winder W*. The winder *W* slits the full-width

sheet and winds it into rolls of proper width to suit the customer, or for further processing. In some cases, the full-width, or *jumbo*, roll is further processed before slitting.

3. Circulation of Stock.—Since water is the medium used to convey the pulp and is essential in forming the sheet, much water is circulated and re-circulated through the paper-machine stock[1] system. The typical flow and course of the stock and white water through the paper machine is shown diagrammatically in Fig. 2. The stock, which has a consistency of about 2½% to 3%,

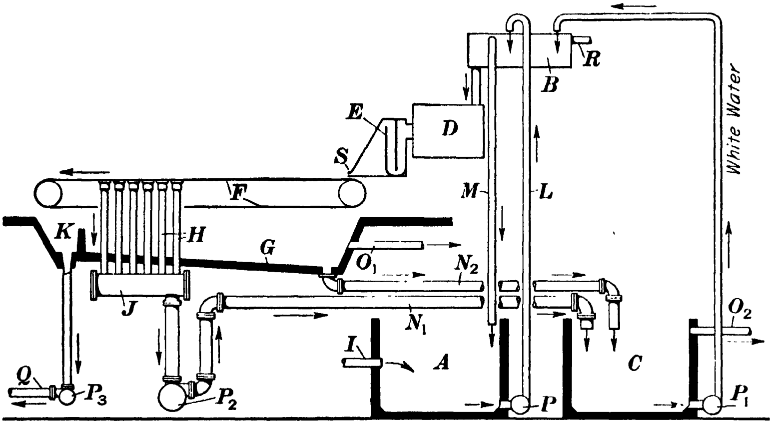


FIG. 2.—*A*, machine (stock) chest; *B*, regulating (mixing) box; *C*, white-water chest; *D*, screens; *E*, headbox (flow-box); *F*, wire; *G*, wire pit; *H*, suction boxes; *I*, inlet from beaters or mixers; *J*, suction-box header; *K*, couch pit; *L*, stock pipe; *M*, stock overflow pipe; O_1, overflow to broke beater; O_2, overflow to beater room; *P*, stock pump; P_1, P_2, white-water pumps; P_3, broke pump; *Q*, broke to beater; *S*, slice; *R*, white-water overflow.

is pumped from the beater stock chest and passed through a Jordan to the *machine chest A* (frequently called a *stuff* or *stock chest*), whence it is delivered by pump *P* to the *regulating* (mixing) *box B*, where it is mixed with the white water that has been pumped from the *white-water box* or chest *C*, in order to dilute the stock to about ½%. An excess of stock is supplied to the regulating box *B*, so as to have the full amount required at all times, and the overflow returns to the machine chest *A*. The diluted stock then goes through the screens *D* (*Y* in Fig. 1)

[1] By *stock* is meant the papermaking fiber of wood pulp, rags, etc., that has been so treated in previous operations that it is in condition to form the sheet of paper. The word *stuff* is also used with the same meaning, but it usually implies paper stock prepared from rags.

on the paper machines, and thence to the headbox (flow-box) E and wire F. A part of the water passing through the wire is again re-circulated through the regulating box to dilute the new stock. The excess white water is used in the beater or in other parts of the mill, or is reclaimed in save-alls.

Modern newsprint, book, and other mills are so arranged that the white water from the wire pit G flows by gravity to the white-water compartment C, and is mixed at that point with stock that has been proportioned and metered by equipment designed for this purpose. The dilute stock is then pumped to the paper-machine screens by a stock or fan pump P_1. A discussion of the details of the equipment, and of the various methods of handling stock to the paper machines, is given later.

AUXILIARY EQUIPMENT

STOCK AND MACHINE CHESTS

4. Stock Chests.—The **machine chest,** frequently called **stock** or **stuff chest,** is usually cylindrical in shape, and may be made of wood, iron, concrete, or tile blocks. The wood chests are sometimes lined with copper or other non-corrosive metal, to minimize dirt and slime trouble, and the concrete tank is often lined with tile for the same reason. A *vertical stock chest,* similar to the one shown in Fig. 3, is the usual equipment for the paper mill. The chest is equipped with a suitable agitator A to keep the stock moving, to maintain the correct consistency, and to prevent the settling or stratifying of the stock. The gear-driven paddle-type agitator here shown is the common type, and it revolves at about 15 to 20 r.p.m. on rag and similar papers. Other methods of agitation, such as a circulating pump, air jets, or a propeller-type agitator, are sometimes used.

The *horizontal stock chest,* Fig. 4, is sometimes used; but it is not well adapted to complete emptying, which is essential whenever different grades of paper, and colored papers, are made. All stock chests should be so designed that they can be easily and quickly washed out and cleaned on changing colors. Wooden chests should be kept full of water during an extensive shut-down period, to prevent shrinkage and leakage.

5. Capacity of Stock Chests.—Vertical stock chests are generally about 12 ft. in diameter and from 6 to 14 ft. deep,

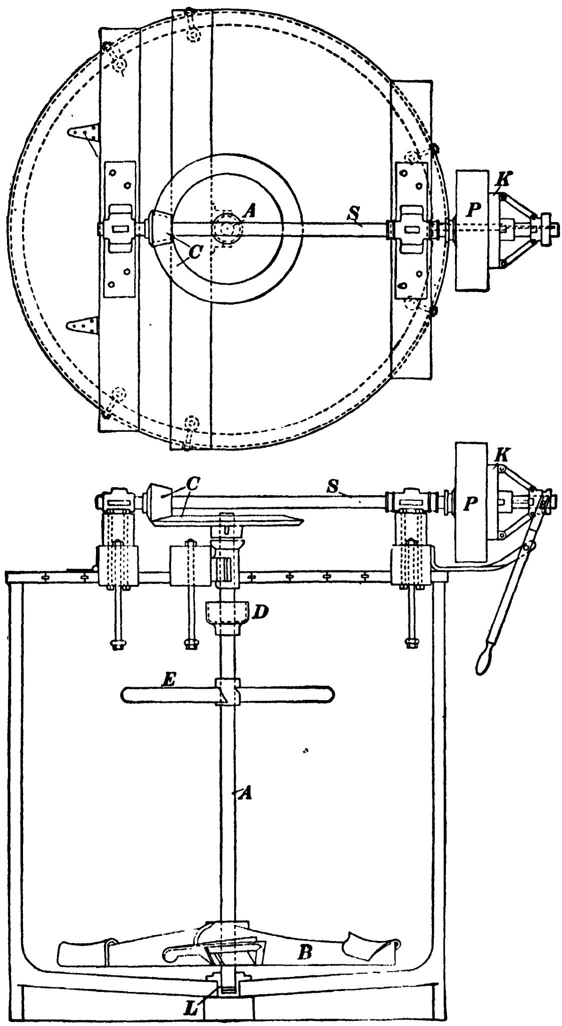


FIG. 3.—*A*, agitator shaft; *B*, agitator blades; *C*, driving gears; *D*, grease catcher; *E*, agitator arms; *K*, clutch; *L*, foot bearing; *P*, drive pulley; *S*, drive spindle.

according to the size of the machine. A stock chest should hold enough to supply the paper machine for an hour or more, and to

give plenty of time for the beaters to replace their contents. If the stock in the chest is allowed to run low between charges from beaters or mixers, it may result in an uneven supply of stock to the machine, which may cause a variation in the weight of the paper. The consistency of the stock in the chest varies from $2\frac{1}{2}\%$ to 3%, but should be kept as uniform as possible by proper control of the beaters, consistency regulators, or other regulating devices.

The size of the chest is readily calculated. For example, suppose a machine is to make 36 tons of paper per day of 24 hours, and it is desired to find the size of a vertical stock chest for the

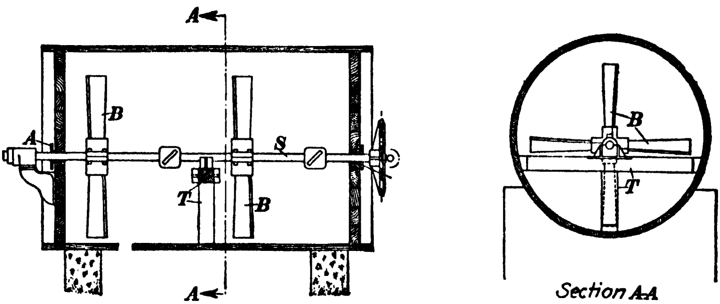


FIG. 4.—*A*, packing; *B*, agitator paddles; *S*, agitator shaft; *T*, inside bearing support.

machine, the consistency being $2\frac{1}{2}\%$. The calculation would be as follows:

$$\text{Average amount of paper per hour} = \frac{36 \times 2000}{24} = 3000 \text{ lb.}$$

$$\text{Weight of stock in chest} = 3000 \div 0.025 = 120{,}000 \text{ lb.}$$

Since stock at this consistency weighs about 62.5 lb./cu. ft., the volume of the chest contents is $120000 \div 62.5 = 1920$ cu. ft. If the diameter of the chest be taken as 14 ft., the inside height of the chest must not be less than $\frac{1920}{0.7854 \times 14^2} = 12.475$, say 12 ft. 6 in.

The following table gives the principal data on the volume and weight of stock at various consistencies; it was calculated on the basis of 1 cu. ft. of stock weighing 62.5 lb., which is sufficiently exact for practical purposes. By *stock consistency*, column 1, is meant

pounds of stock per 100 pounds of liquid; by gallon is meant the U. S. gallon of 231 cu. in.

STOCK CONSISTENCY, WEIGHT, AND VOLUME

Stock consistency	Pounds of stock per cubic foot of liquid		Cubic feet of liquid per pound of stock		Gallons of liquid per pound of stock	
	Air dry	Oven dry	Air dry	Oven dry	Air dry	Oven dry
0.25	0.1562	0.1406	6.400	7.111	47.88	53.19
0.50	0.3125	0.2812	3.200	3.556	23.94	26.60
0.75	0.4687	0.4218	2.133	2.370	15.96	17.73
1.00	0.6250	0.5625	1.600	1.778	11.97	13.30
1.25	0.7812	0.7031	1.280	1.422	9.574	10.64
1.50	0.9375	0.8437	1.067	1.185	7.979	8.866
1.75	1.0937	0.9843	0.9143	1.016	6.839	7.599
2.00	1.250	1.125	0.8000	0.8889	5.984	6.649
2.25	1.406	1.266	0.7111	0.7901	5.319	5.910
2.50	1.562	1.406	0.6400	0.7111	4.787	5.319
2.75	1.719	1.547	0.5818	0.6465	4.352	4.836
3.00	1.875	1.687	0.5333	0.5926	3.990	4.433
3.50	2.187	1.969	0.4571	0.5079	3.420	3.800
4.00	2.500	2.250	0.4000	0.4444	2.992	3.325
4.50	2.812	2.531	0.3556	0.3951	2.660	2.955
5.00	3.125	2.812	0.3200	0.3556	2.394	2.660
5.50	3.437	3.094	0.2909	0.3232	2.176	2.418
6.00	3.750	3.375	0.2667	0.2963	1.995	2.216
6.50	4.062	3.656	0.2462	0.2735	1.841	2.046
7.00	4.375	3.938	0.2286	0.2540	1.710	1.900
7.50	4.697	4.228	0.2133	0.2370	1.596	1.773
8.00	5.000	4.500	0.2000	0.2222	1.496	1.662

In the foregoing example, the weight of paper produced per hour was 3000 lb. From the table, at 2.5% consistency, 0.64 cu. ft. of liquid contains 1 lb. of air-dry stock; hence, the volume of the stock chest must be at least 3000 × 0.64 = 1920 cu. ft.

STOCK PUMPS

6. Types of Pumps.—Pumps of both the plunger and centrifugal type are used to pump stock from the machine (stock) chest to the paper machine; they are also used to pump broke and for other pumping purposes. The centrifugal pump has been largely adopted by the modern mill, particularly where the volume of

stock, consistency, and operating conditions are at a reasonably constant rate. The open impeller type handles the heavy stock to the machines, and gives a continuous and even flow. It is necessary to keep a constant supply of stock at the inlet side of a centrifugal pump, and also to provide a vent to prevent air binding and interruption of service.

The plunger pump may be single, duplex, or triplex, depending on the service; the action of this type of pump is positive if properly installed and operated. For some types of service, where the supply of pulp is intermittent, the plunger pump is selected by the modern mill. It is not good practice to drive these pumps over 30 r.p.m., and the seats and balls must be kept in good condition for best operation.

A quite complete treatment on the subject of pumps will be found in *Auxiliary Mill Equipment*, Vol. IV.

7. Size of Pump.—The average consistency of the stock in the machine (stock) chest is about $2\frac{1}{2}\%$; in other words, the stock is $100 - 2.5 \times 0.9 = 97.75\%$ water. This is a ratio of water to fiber of about 43 to 1. In calculating the capacity of a pump, it is advisable to provide for additional volume in case the consistency be lowered by dilution. In the following example, a ratio of 50 to 1 has been used.

Suppose the machine to make 50 tons of paper per day of 24 hours; this is at the rate of $\frac{2000 \times 50}{24 \times 60} = 69.44$ lb./min. Taking the weight of a gallon of stock as $8\frac{1}{3} = \frac{100}{12}$ lb., the capacity of the stock pump must be $\frac{69.44 \times 50 \times 12}{100} = 417$ gal./min. A stock pump must have a capacity in excess of the paper equivalent, in order that a constant head may be maintained on the discharge orifice of the regulating box, the overflow from the regulating box returning to the stock chest. Therefore, 20% should be added for a centrifugal pump to provide for the overflow and trim of the paper, and 25% should be added for a plunger pump for the same reason. The 5% additional in the latter case is an allowance for the *slip*, which does not occur with a centrifugal pump. In this case, the capacity of a centrifugal pump would be $417 \times 1.2 = 500$ gal./min., and of a plunger pump $417 \times 1.25 = 520$ gal./min.

8. Horsepower of Stock Pumps.—When calculating the horsepower required to operate a stock pump, it is important to remember that the resistance to flow is often $2\frac{1}{2}$ times as great as when pumping water, because of the increased friction in the pipes, which increases very rapidly with the consistency. The total head is equal to the vertical distance between the point of discharge of the pump and the point of delivery at the regulating box, called the *static head,* plus an additional friction head required to overcome friction, allow for bends, etc. For general calculations, the friction head may be taken as equal to the static head, to allow for all possible contingencies. If there is a suction lift, this should be added to the static head; but if there is a pressure on the inlet, it should be subtracted from the static head. The subject is thoroughly discussed in *Auxiliary Mill Equipment,* Vol. IV.

Assuming that a plunger pump is to deliver 520 gal./min. and taking the static head as 20 ft., the total head may be considered as $20 \times 2 = 40$ ft. and the theoretical horsepower is $\frac{520 \times 100 \times 40}{33000 \times 12} = 5.25$ hp. The efficiency of a stock pump will vary between 50% and 85%, depending on pumping conditions, type, and design. Hence, the probable actual horsepower of this pump will vary between $5.25 \div 0.50 = 10.5$ hp. and $5.25 \div 0.85 = 6.2$ hp.

THE REGULATING BOX

9. Functions of the Regulating Box.—Two important functions of the **regulating box** are: first, it regulates the *amount* of stock going to the paper machine; second, it regulates the *consistency* of the stock going to the paper machine. The amount of stock is regulated by so operating a gate or valve that just the right amount of the stock pumped from the machine chest is delivered to the mixing compartment or mixing box. The consistency of the stock is regulated by controlling the amount of water (usually white water collected under the wire) with which the stock is diluted. The amount of actual fiber delivered by the pump varies with the consistency in the chest; and the extent of the dilution must be changed in accordance with the freeness of the stock and the speed of the machine. A slow stock requires less dilution, because the water stays longer with this type of fiber.

10. Uniformity of Weight of Paper.—In the earlier types of regulating box, the machine tender changed the amount of stock going to the machine when he wished to vary the weight of the paper, or when the weight had accidentally changed, on account of the stock in the chest having become thicker or thinner. Likewise, the amount of water added to the stock was changed in accordance with its behavior on the wire, especially during the formation or interweaving of the fibers. This is only one of several adjustments that may have to be made. In order to get more dependable uniformity, several automatic regulating boxes have been devised, and are in use on most modern machines.

The principal factor in securing uniformity of weight is uniformity of the consistency. As pointed out in the Section on *Beating and Refining*, the logical place to control the consistency is when the stock passes the Jordan on its way to the machine chest. By keeping the consistency uniform, regulation at the machine is greatly simplified.

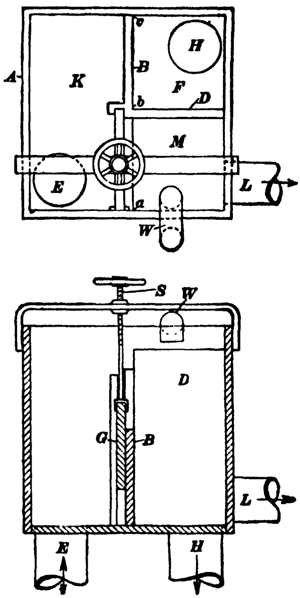


FIG. 5.

11. A Simple Regulating Box.—A very simple regulating box is shown in Fig. 5. The stock pump discharges through pipe E into compartment K. An adjustable gate G admits the required amount of stock to the mixing compartment or box M, in which it is diluted and mixed with white water. The amount of the white water admitted is controlled by a valve on pipe W, set by the machine tender in accordance with the condition of the stock. The excess stock flows over partition B into compartment F, and goes back to the stock chest through the overflow pipe H. There is usually a gate on the discharge L to the sand trap, screens, and machine. If the consistency of the stock is uniform, this gate can be made to control the amount furnished the machine, since, with a constant head, the volume delivered depends only on the size of the outlet.

12. Conditions Governing Automatic Regulation.—Automatic regulation involves mechanical regulation at one or more of four points: (1) admission of white water at intake of stock pump; (2) operation of gate *G*, Fig. 5; (3) control of valve admitting white water to mixing box; (4) operation of gate at *L*. The principles generally involved are: the resistance to immersion of a float, which varies with changes in the consistency of the stock; the friction of the stock as it passes through a pipe, which varies with the consistency of the stock; the slight change in weight of a unit of volume of stock, which results from changes in consistency.

The advantage of a mechanical automatic regulator is that variations in stock consistency are detected and corrected *before* the stock goes to the machine. The machine tender would not be aware of these variations until a sample of the finished paper was weighed. However, the use of a mechanical automatic regulator does not relieve the machine tender of the necessity of making proper adjustments when changing the basis weight of the sheet, its width, speed of the machine, or in preserving the general character of the sheet on the wire.

13. Regulating the Consistency.—The consistency regulator was illustrated and explained in the Sections on *Treatment of Pulp*, Vol. III, and in *Beating and Refining*, Vol. IV. The regulator there described will control the consistency of the stuff going to the machine chest to within 5% of the consistency desired. This is accomplished by keeping the stock a little too thick in the beater or beater chest, and by controlling the amount of white water or fresh water admitted to the suction side of the stock pump. With stock of accurately controlled consistency, all that is necessary is that the machine tender set his valves and gates for the amount of stock and diluting water that accords with the speed of the machine and the character of the stock. Variation in weight can then occur only because of mechanical trouble with the drive.

14. Proportioning and Metering System.—This system is designed to give constant and uniform proportions of the various papermaking ingredients, and to deliver them as a thorough and complete mixture to the Jordans or to the machine chest. The groundwood and sulphite coming to their respective compartments *A* and *B*, Fig. 6, should be brought to a uniform consistency

of about $2\frac{1}{2}$ % to 3 % by means of automatic consistency regulators (Art. **15**), and the color, alum, etc., should be dissolved and furnished at a given concentration.

The stock meters *C*, Fig. 7, consist of cylindrical barrels, bored to size, and fitted with 4-arm rotors—like revolving doors—the tips of which are provided with rubber strips to give a seal, and, at the same time, to be flexible enough to allow small pieces of foreign materials to pass through without injury to the apparatus. Similar small meters are provided for solutions of alum, color,

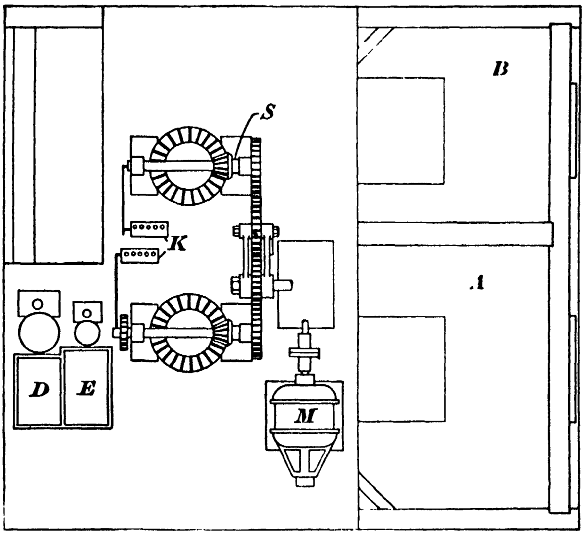


FIG. 6.

etc.—as at *D* and *E*, Fig. 6—which can flow by gravity to their respective compartments, being controlled by float valves, thus rendering it unnecessary to provide an overflow and pumps to return this overflow, except when using clay or other filler. The storage for clay should be in the basement, with the supply pumped to the system and an overflow returning to the storage tank. There is an overflow, either in place of, or in addition to, the float valves *F*, Fig. 7, from both the groundwood and sulphite compartments returning to their respective chests, though this is not necessary, since the float valves will so control the admission of stock as to keep the compartments at the proper levels.

The meters are geared together; and as each will allow only a definite volume to pass through at each revolution, it is evident that, if the consistencies are kept uniform, a perfectly uniform mixture of paper stock will be obtained. Rotating measuring vanes *C* are sometimes on a horizontal shaft.

The total volume of stock discharged is controlled by means of a variable-speed motor *M*, Fig. 7, and the relative proportions of

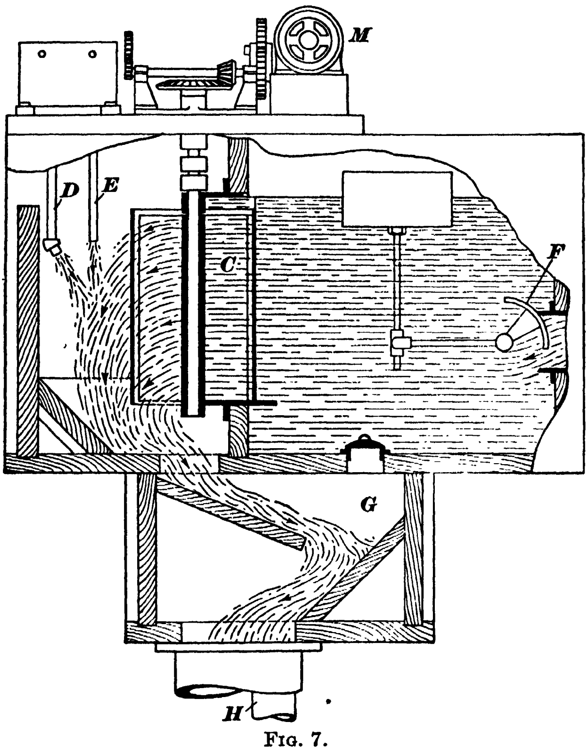


FIG. 7.

groundwood and of sulphite are changed at will—in a few moments' time—by changing a Reeves drive to the sulphite-meter shaft. Alum, color, etc., have each a separate thumb-screw adjustment, so the proportions of these ingredients can be quickly changed as desired, and without shutting down the apparatus.

The stock and liquids discharged by the different meters mix thoroughly in the mixing compartment *G* beneath the vat, and go to the Jordan or to the machine chest as a uniform paper stock.

The use of a machine stock chest practically insures the smoothing out of momentary variations in stock consistency.

The revolution counters *K*, Fig. 6, attached to the groundwood and sulphite meters, record the amounts of each kind used in a given time, thus enabling a mill to use all slush stock, and at the same time, to know how much of each kind of pulp has been used.

In earlier installations, the proportions of the stocks used were controlled by adjustable-width gates, through which the stock flowed under constant head. The gates are so connected that when one is opened—say to increase the sulphite pulp—the other

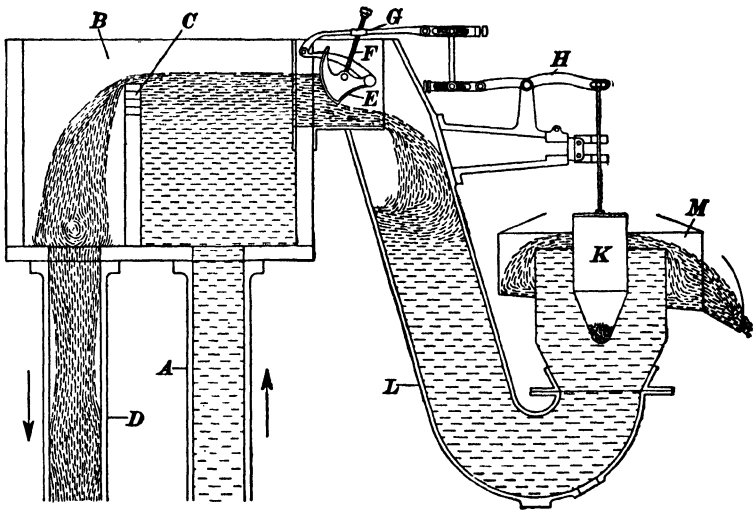


FIG. 8.

closes a corresponding amount, so as to decrease the groundwood. The consistency of each stock is, of course, kept constant.

15. Automatic Regulator.—In Fig. 8, a regulator is shown which has been designed to regulate the volume of stock furnished the machine as the consistency varies, in order that the weight of fiber supplied to the machine may be constant. Delivery from the stock chest is through the pipe *A* to box *B*; any excess flows over the dam *C* and is pumped or flows by gravity back to the machine chest through pipe *D*. The stock for the machine passes the adjustable gate *E*, which is moved by pin *F* and levers *G* and *H*, the latter being actuated by the float *K*. The stock passes down the spout *L*, works up around the float *K*, and passes into

the annular ring *M*, from which it flows to the machine. The float may be weighted according to the usual consistency of the stuff; it sinks in thin stuff, and it is raised by the friction and greater density of thick stuff, thus opening or closing the gate *E* accordingly. No outside power is required to operate this mechanism, which is very simple. The amount of white water or fresh water used to dilute the stock must be regulated by other means.

16. Automatic Stock Box.—The regulator shown in Fig. 9 is called an **automatic stock box.** Stock from the chest enters compartment *A* and leaves it through outlet *F*, which is so

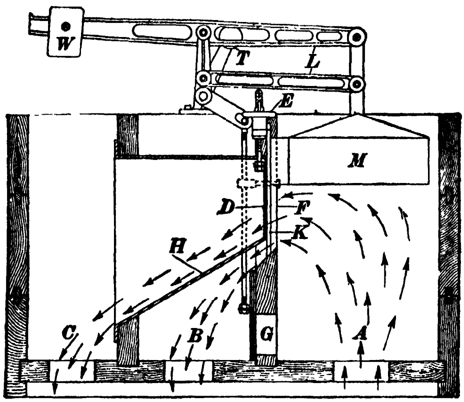


FIG. 9.

divided by the bottom of spout *H* that a part or all of the stock may go either to the overflow or back to the chest through *B*, or it may go to the machine through *C*. A clean-out gate is shown at *G*; it is operated by handle *T*.

The relative proportions of the stock going through *B* and *C* are controlled by the dividing gate *K*, which lets more stock into *B* or *C*, according as this gate is raised or lowered. The movement of gate *K* is caused by the float *M*, which is suspended from the levers *L*. When the stock is coming through, the gate *D* is so adjusted by means of the hand wheel *E* that the required amount goes to the machine and the remainder goes back to the chest. The float is counterpoised by the weight *W*, which is adjusted to balance the float in stock of the proper consistency. If the stock becomes thicker, and therefore less fluid, its buoyant action is

increased, the float rises, and the gate K, which is attached to it, also rises; the changed opening thus obtained admits less stock to the machine and more to the chest. If the stock becomes thinner, more fluid, more of it will then be required on the machine; its buoyant action then decreases, and the float M falls. This causes the gate K to move downward, partially closing the opening to the chest, which sends less stock to the chest and more to the machine. The stock may be thinned to the proper state of dilution for machine operation by adding water at any convenient point after the stock leaves the stock box. The regulation of this water is not provided for in this apparatus, since the slight change in the flow of stock required to maintain uniform weight of paper would make a hardly perceptible change in the density of the stock on the wire.

WHITE WATER

17. Rich and Lean White Water.—When the stock goes onto the Fourdrinier wire at a consistency of, say, $\frac{1}{2}\%$ to 1%, water goes through the meshes of the wire and carries with it a certain percentage of fine fibers. This so-called **white water** flows into the save-all pans, trays, or pit under the wire, and then flows back to the mixing box, where it is used to dilute the new stock being supplied to the machine. White water may be 'rich' in fibers, such as that coming from the wire near the headbox or from the wet flat suction boxes. The 'lean' white water, which contains a smaller percentage of fibers, is removed from the sheet by the dry flat suction boxes and the suction couch roll. A large proportion of the white water is in constant circulation through the paper machine, and it is often an important factor in the formation of the sheet on the wire.

The richness, or high-fiber consistency, of white water will vary greatly with the character of the stock. Where sulphite or other long fiber chemical pulps are used with little or no filler, the white water will contain a small percentage of small fibers; but if considerable groundwood or other short-fiber pulps are used in the sheet, the white water will be quite 'rich.'

It is essential to utilize white water on the paper machine, in the beaters, on the deckers, or wherever possible, in order to reduce fiber waste in the mill.

18. Paper-Mill White-Water Flow Diagram.—A diagram of a typical newsprint paper-mill system for machines having trays is given in Fig. 10, and is shown with tray and suction water sup-

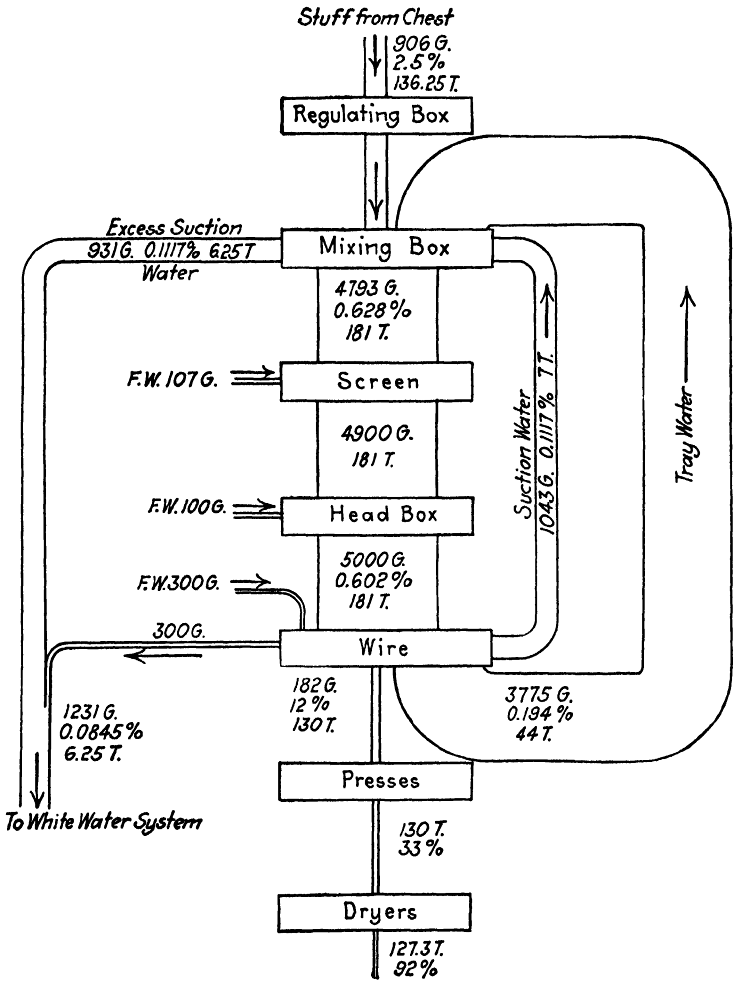


Fig. 10.

plied to a mixing box having baffles so arranged that all the tray water is used before any of the suction water. The supply to the machine includes groundwood and sulphite pulp, the defibered paper, or broke, and the recovered stock from the excess white

water. The stock is shown as air-dry consistencies up to the dryers, purposely to bring out the apparent shrinkage between the air-dry pulp and the finished paper. This diagram shows where and how much fresh water is added, how much white water is removed, how much fiber is contained in it, and where it re-enters the system or is discharged. The width of the stream is proportional to the volume. Of course, if consistency figures vary from those given—and they usually will—the volume of water flow must be changed in proportion.

In this diagram, which is drawn for a 120-ton newsprint unit, the following abbreviations are used:

F. W. = fresh water.
G = gallons per minute.
% = consistency, air dry.
T = tons per 24 hours, including broke.

A sulphite-mill system serves as a good outlet for excess paper-mill white water. For a 25-ton pulp mill, 500 to 600 gallons per minute of the paper-mill water carrying, say, 3 tons of stock, could be used to advantage. Under this condition, the loss from the sulphite mill will be greater; but, still, about 80% of the stock in the paper-mill water will be retained with the sulphite stock. The use of this paper-mill water also may necessitate added deckering or pressing equipment for the sulphite, mainly because of slowing up the stock.

PAPER-MILL SAVE-ALLS

19. Reclaiming White Water.—The reclamation of the excess white water is essential to the economical operation of the paper mill. The fiber and filler reclaimed by the various types of save-alls and reclamation systems may amount to between 2% and 10% of the materials furnished to the paper machines. In order to manufacture paper at a minimum cost, the modern paper mill must be properly equipped with a save-all system and other accessories. As an example, an excess sewer loss of 5% of fiber and filler in a mill of 500 tons daily capacity, making high-grade chemical book papers, might result in the equivalent loss of, perhaps, $250 per day, or $75,000 per year.

20. Types of Save-Alls.—The type of save-all system and equipment will vary with the character of the stock used and the layout of the plant. There are three general types, involving fundamental principles of fiber and filler reclamation, as follows: (1) stationary and revolving-screen save-alls; (2) vacuum-filter save-alls; (3) settling or sedimentation tanks.

The common type of **stationary save-all** is the inclined screen. Though simple and cheap to construct and operate, it usually reclaims only about 50 per cent of the stock, and it may be expensive in the long run, except where used on long-fibered chemical pulps. The **revolving screen,** or **cylinder type,** of **save-all** is likewise best adapted to long-fibered pulps where used solely as a save-all. This machine also has a low efficiency, about 50 per cent, except when installed in a general system that provides for the addition of new pulp to function as a mat on which the shorter fibers can be collected and returned to the system.

The principle of the **vacuum-filter save-all** has been generally adopted for most kinds of pulp. It is particularly efficient where the entire save-all system has been developed with the pulp-washing and deckering system and the new pulp functions as a mat or filter medium for the white water. The effluent or waste from a well-arranged system using vacuum filters is often less then 1 per cent, which is considered very excellent operation. The vacuum filter is also successfully used on individual paper machines making a variety of grades and colors.

The **sedimentation-tank type** of save-all is fairly well adapted to stock that contains a high percentage of clay or other filler. The heavy mineral materials help in settling out and reclaiming the valuable papermaking materials, and tanks of adequate size and design are efficient. However, they are not very effective on other types of stock, and are not considered a good general type of save-all.

Some of the general types of save-alls will now be described.

21. Cylinder Type of Save-All.—Several types of save-alls are fully described in the Section on *Treatment of Pulp*, Vol. III, one of these being here shown in Fig. 11. This is the **decker type** of save-all, and is similar in principle to the standard groundwood and sulphite deckers. A cylinder 4, covered with fine wire, is

revolved in a vat 8, into which the white water flows, generally by gravity, through inlet 7. The white water flows through the fine wire covering of the cylinder mold, leaving the suspended fibers clinging to the outside surface. As the surface of the revolving cylinder emerges from the dilute stock, it passes under a soft couch roll 2, which picks off the adhering fibers from the wire. The pulp fibers are taken off the couch roll, scraped by a wooden doctor 1, and guided by a board 3 into a passage 10.

A variation of this type of cylinder save-all is used by the application of a felt that covers the wire cylinder. The felt-covered cylinder is little used at the present time, because of its low capacity and high upkeep cost.

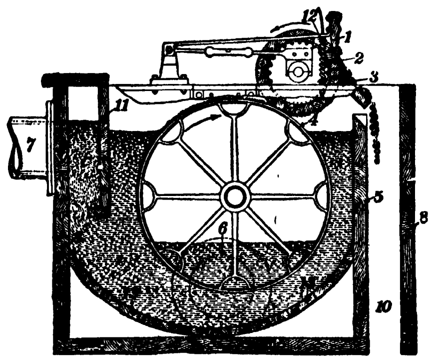


FIG. 11.

22. Vacuum-Type Save-Alls.—The **drum,** or **cylinder, type** of vacuum filter is largely used on white water, as well as for deckering, washing, or dewatering pulp stock. The **disk type** of filter is no longer employed to any great extent. The usual layout when using the vacuum filter as a save-all is to mix sufficient new pulp, usually sulphite, with the white water being fed to the vat of the filter to deposit a thin filtering medium on the wire.

If the filter is primarily used as a decker and the white water mixed with the chemical pulp, the efficiency of this equipment is very high.

In the operation of the drum type of filter, Fig. 12, the cylinder rotates in a vat filled with dilute stock that has been thinned with white water.

When using filters for the recovery of white-water fiber only, it is advisable to add a small portion of longer fibered stock to the white water handled, in order to form the filtering mat required to produce a clear filter effluent. This longer fibered stock is simply 'borrowed,' and is returned to the system, together with the recovered white-water fiber. As the stock contained in the surplus white water from the paper machines can be returned to the beater, Jordan, or machine chest, stock ready for the furnish can be used as so-called 'borrowed' stock to act as a filter medium. The system, therefore, can be self-contained for each paper machine.

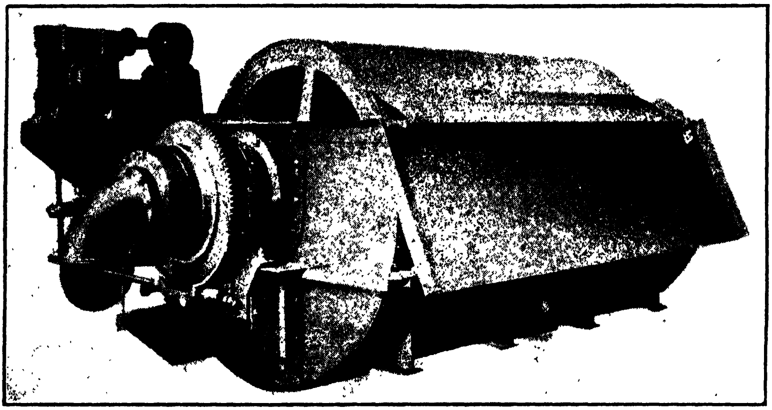


FIG. 12.

Continuous vacuum filters have a high recovery; they occupy little space, and, owing to the small amount of pulp contained in the filter vat, orders can be readily changed on the machine, with loss of very little fiber during the change. If desired, the clear effluent can be used for the paper-machine showers, with small possibility of plugging difficulties.

A cylinder-type save-all is shown in Fig. 12. The vat is shaped to the cylinder that revolves therein, and the face of the cylinder is divided into a number of sections, which are individually connected to an automatic valve by means of a manifold. As soon as a section is completely submerged in the white water, vacuum is automatically applied to that section, and thus a sheet of pulp is instantaneously formed. Thereafter, the rest of the water filtered passes through this sheet of pulp and is conse-

quently comparatively free from fiber. The degree of submergence of the cylinder varies from 50 to 60 per cent, depending on the stock being handled. The exposed part of the cylinder is also under a vacuum, which thus partially dries the sheet; but the vacuum is shut off at varying points, in order to permit the stock discharge to be at a proper consistency.

Either a doctor or a couch roll is employed to remove the stock from the cylinder. On certain occasions, an air blast or jet of water is used to lift the sheet of pulp just before the section has reached the doctor. The save-all is driven by means of a small motor through a worm-gear speed reducer and chain drive. The vacuum is usually induced by means of a barometric leg; but where sufficient fall is not available, small vacuum pumps are used.

In all these machines, with the exception of the save-all where the felt is used, there is still considerable loss of the filling materials, such as clay, because these find their way through the mesh of the cylinder-wire covering.

23. Settling Tanks.—A type of save-all that is largely used in book-paper mills, or where considerable clay or other filler is used in the paper, is called the **settling,** or **sedimentation, tank.** Its installation cost is expensive; but this is compensated for by the small cost of operation, upkeep, and repair, with no part to wear out or require renewing.

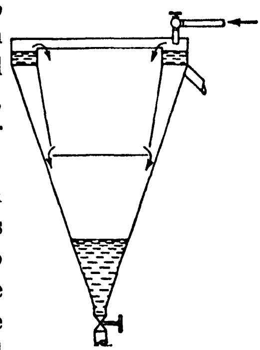


FIG. 13.

To take care of all the white water from a pulp or paper mill, the settling tanks must be of large proportions, in order to give all the white water sufficient time to stand long enough to settle. In some cases, the white water is distributed around an annular trough, Fig. 13, running on the outside circumference of the tank. When full, this annular trough allows the white water to flow slowly over into the tank, so as to prevent any undue agitation and permit the maximum settling effect. This type of save-all is made conical in shape, the apex of the cone being the lowermost point, at which the sediment is removed through a valve.

Fig. 14 shows a more modern type, in which the white water enters at the center and flows outwardly into a series of annular troughs until it reaches the outer trough, where the solids finally settle in the bottom of the inverted cone.

The settling type of save-all possesses the advantage of allowing the reclaimed stock to be pumped back into the system. Settling tanks must be large enough to permit their uninterrupted operation, in order that the white water may flow continuously into the tank while the reclaimed stock and clear water are flowing away continuously and separately. This requires that the tanks be about 20 feet in diameter and that the cone be about the same height, though even larger dimensions are preferable. The settling tank does not work right until it becomes full of white water, when the incoming water comes quickly to rest on top of the large body of water beneath it, and then the suspended matter begins to settle at once.

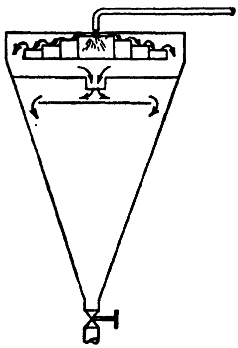


FIG. 14.

24. Inclined-Wire Save-Alls.—A commonly used type of save-all, which is made in many different forms, is an inclined screen of fine mesh wire; it is easily built in the mill at a reasonable cost, and requires little or no power to drive it. It is sometimes given a slight motion, and it requires only intermittent attention. The reclaimed stock can be pumped back into the system in the same manner as in the settling tank, the wire screen replacing the settling action. The angle of the wire is usually about 38°, and the headbox should be so arranged as to give a smooth, even flow onto the wire.

Fig. 15 shows diagrammatically the conventional type of **inclined-screen save-all.** In the illustration, *A* is the white-water supply pipe, *B* is the headbox, and the white water flows to the inclined wire *D* through the slots *C* in the headbox. The thickened stock rolls down into the stock box *E*, and through the discharge pipe *F* back to the system, to be re-used. The white water collects in the chest *G*, and passes through pipe *H* back to the system again, or to waste, in accordance with the design of the white-water system.

This type of save-all can also be used as a decker for groundwood or sulphite.

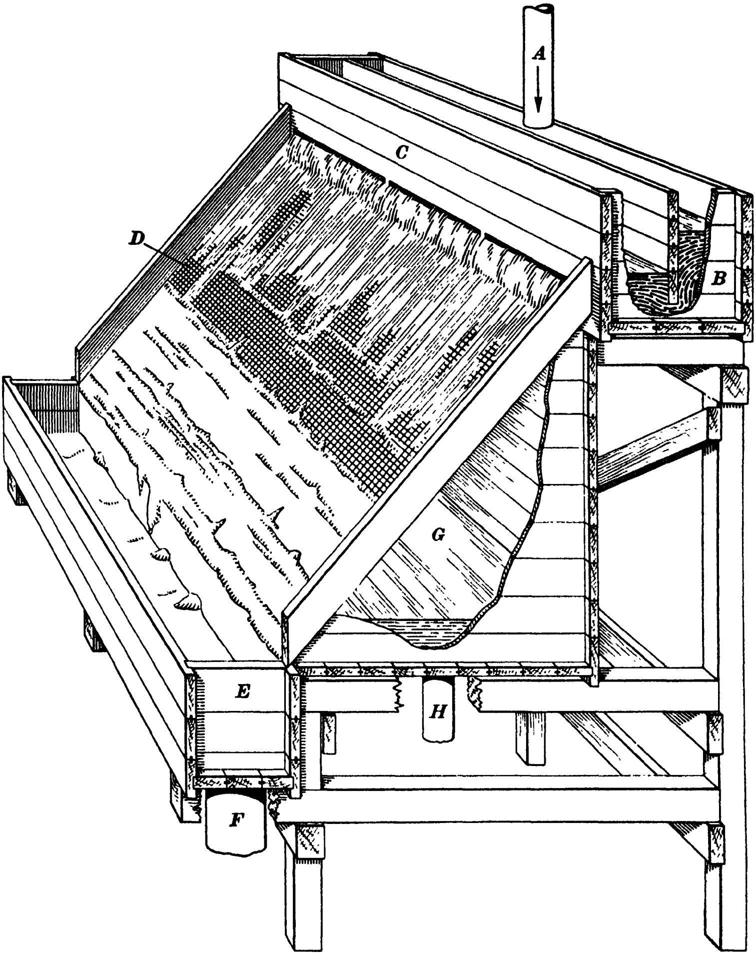


FIG. 15.

RIFFLERS, OR SAND TRAPS

25. Construction.—**Rifflers,** or **sand traps,** are wood troughs through which the stock flows from the regulating box to the screens on the paper machines that require special treatment of the pulp for high-grade papers. Modern screening methods

have, to a large extent, eliminated the use of the riffler connected with the paper machine. The riffler is now more commonly used in the pulp mill after the screens, or just before the stock goes to the deckers. Rifflers vary in length and shape, according to the capacity required to handle the stock being used.

The bottom of the trap (riffler) is divided into sections by transverse strips of wood, which are frequently so inclined that their faces lean against the flow of the stock; this helps in the retention of dirt, or sand, as it sinks to the bottom of the riffler. In some narrow boxes, the wood strips are replaced with strips of zinc, slipped into slots in the sides of the trap: these can easily be removed for cleaning. The depth of the riffler, or sand trap, is from 18 to 20 inches, and the width is from 18 inches to 8 feet. The narrower sizes are usually of greater length, say from 30 to 50 feet. The wider traps are seldom over 15 feet long, and are sometimes used in the preparation of fine writing and bond papers. The bottom of the trap is occasionally covered with old felt, to catch and hold the dirt.

Since the principle of the riffler involves the effectiveness of the settling of foreign materials slightly heavier than the pulp, the velocity of flow must be sufficiently low to permit proper settlement of sand and other materials. The type of stock, as well as its consistency, will affect the settling action; but, under average conditions, the surface speed of the stock flowing over a riffler should be between 8 and 15 feet per minute.

26. Two-Run Rifflers.—Fig. 16 shows one type of riffler, or sand trap. The mixed water and fiber flows into the riffler through pipe *A*, and the pitch (slope) of the bottom of the riffler is only about 1 inch in 14 feet. This riffler is divided into two runs by the central dividing board *D*, the total length of run of the stock being about 28 feet, and the width of each run being about 18 inches. The discharge pipe *C* leads to the screens. When the riffler is to be cleaned, the discharge pipe *C* is disconnected, the supply pipe *A* is put to one side, the riffler is turned on its side, and the dirt washed out with a hose.

Other types of rifflers are illustrated and explained in the Section on *Treatment of Pulp*, Vol. III. Since rifflers are often made at the mill, local ideas and conditions may affect their construction.

27. Rifflers with Electromagnets.—Paper stock that is prepared from rags is likely to contain small particles of iron; this may also occur when waste papers stitched with wire are used. Particles of iron may likewise be present by reason of the abrasion of beater and Jordan bars. These particles can be almost entirely removed from the diluted stock by placing an electromagnet across the riffler, just before the stock goes to the screens. When this is done, it is a good plan to make the riffler at this point a wide, short box, in which the magnet is placed, in order to have a shallow stream of water flowing over the magnet.

28. A Centrifugal Sand Separator.—In the sand trap, or riffler, the heavy dirt particles separate by gravity from the lighter

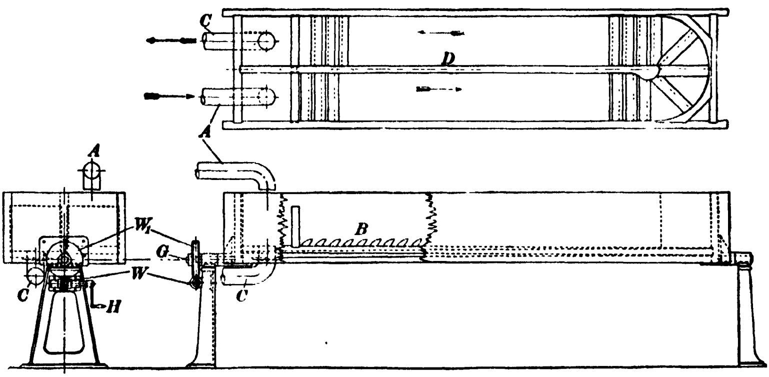


FIG. 16.

fibers in the flowing stream of stock. In the machine shown in Fig. 17, the principle of centrifugal force is utilized. Centrifugal force is more powerful than gravity, and is controllable.

In the casing *K* is a revolving unit consisting of a cylindrical basket *C*, an inverted-funnel feed tube *F*, a skimming ring *R*, and a shaft *S*, driven by motor *M* through friction clutch *D*.

Stock feeds through trough *T* and enters the center feed tube *F* tangentially. The speed of the feed tube spreads the stock evenly within the tube and distributes it with some initial velocity to the wall of the basket *C*, where it immediately acquires the peripheral speed of the basket and rises evenly on the basket wall. The first baffle ring *A* causes a mat of stock to be formed in the lower section of the basket; here the separation of the heavier impurities immediately takes place.

Baffle *B* forms a second mat, and any heavy impurities that have passed the lower section are caught here. The top section of the basket is slightly larger in diameter; hence, the separating force here is still greater, and even the finest of the heavier impurities that may remain in the stock are separated at this point. Light material of the nature of shives and rubber, because of their light weight, float on the surface of the stock

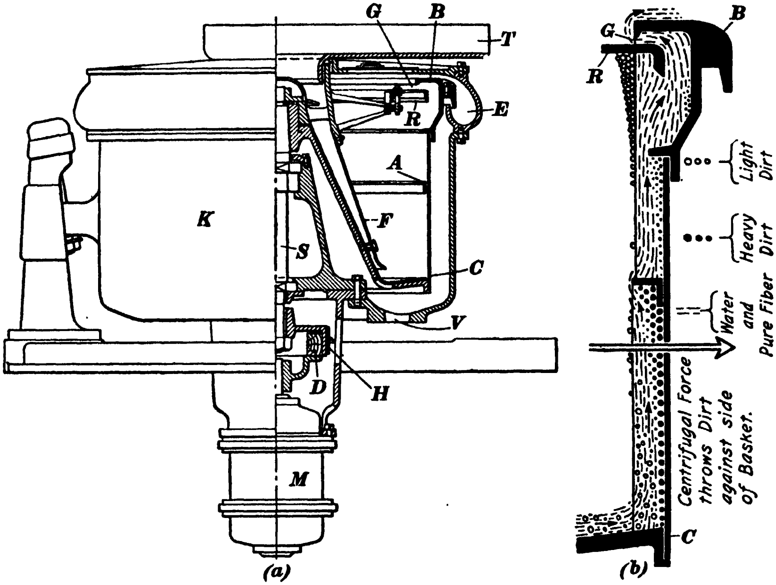


Fig. 17.—View (*a*) is a sectional drawing of the centrifugal separator. View (*b*) is an enlarged section of the revolving basket *B-C*; it shows the flow of stock and the process of purification.

nearest the center of the machine; as these rise, they are trapped and collected by skimmer ring *R*.

The stock, now thoroughly separated from the lighter and heavier impurities, passes through the adjustable discharge opening *G* into the stationary collector trough *E*, and then to the screens. The stock passes through the separator rapidly and continuously. The concentration varies, according to character of the paper, from 0.4 to 1 per cent.

Impurities removed from the stock are retained in the basket; they are washed out at regular intervals averaging 8 to 12 hours. When cleaning is required, the machine is shut down (a brake *H*

is provided for bringing the basket to a quick stop), and all material in the machine is washed out through openings *V* provided in the bottom of the machine casing.

SCREENS

29. Diaphragm Screens.—Before the paper stock finally enters the flow-box, or *headbox*, as it is frequently called, ready to flow onto the wire of the paper machine, it is screened, for the purpose of removing as much as possible of the dirt, lumps, slivers, etc., which may be present and may have resulted from, or escaped during, the process of preparation. Both the **flat,** or **diaphragm,** and the **rotary** types of **screens** are used at this stage of manufacture. In either case, a difference in level between the inside and the outside of the screens causes the water in which the fiber is suspended to pass through a slotted or perforated plate.

In Fig. 18, the diaphragm screen is made to take 10, 12, or 14 plates, usually of bronze, which are 12 inches wide, 43 inches long, and about $\frac{3}{8}$ inch thick. These plates 12 form the top of a shallow box, the bottom of which is made up of a series of rubber diaphragms 22, which are supported on boards 14 and are separated by wood spacers 21, which, together with the strips 30, support the plates. The top of this shallow box is the bottom of the screen box, the sides and ends of which are numbered 10 in the illustration. The screen box rests on the frame 18, to which the diaphragms are nailed. The box and frame are clamped together by long threaded bolts (screen bolts) in such a manner as to make a tight joint all around. Two socket joints are provided on one side, so the box can be raised at intervals and washed with a hose. The diaphragms, which give the screen its name, are fastened by air-tight joints to the sides and ends of the box and to the cross beams 19. Rods 5, attached by blocks 23 to the centers of the diaphragm boards 15, and bearing at their lower ends a hardwood toe block 7, ride cams 8, which have three or four corners. The cams are mounted on a shaft 2, which revolves at 125 to 175 r.p.m., thus agitating each diaphragm either three or four times for each revolution of a cam. The cams are so mounted on the shaft that their strokes alternate with one another. The hardwood blocks, usually maple, are held by clamps 9; they are removable, since they require replacing as they wear out. The blocks are restrained

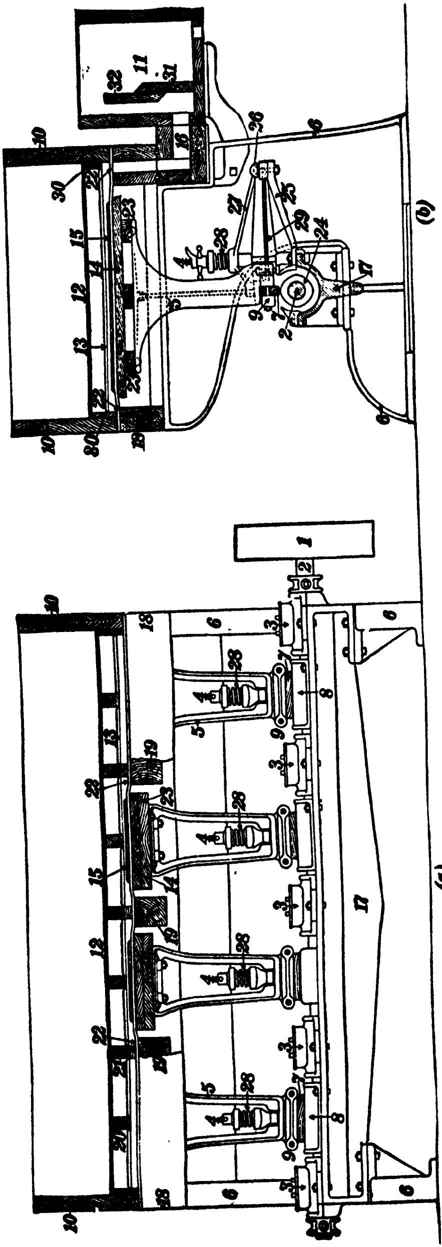


Fig. 18.

from jumping away from the cams by the springs 27 and 28, and by the adjusting nuts 4. In recent designs a rod, connecting the diaphragm plate 15 and actuated by an eccentric on shaft 2, replaces the awkward, noisy mechanism 25-7-8-9-4-25-26-27-28-29. The improved vibrating mechanism is practically noiseless and requires very little power.

The size of the slots in the screen plates depends upon the kind of paper being made, their width ranging from 8 to 25 thousandths of an inch (0.008 to 0.025 inch); they are referred to as 8 cut, 25 cut, etc. The slots are wider at the bottom than at the top, and are cut about four or five to the inch; their length is about 4 inches. The screen is made with an adjustable dam 31, 32 at the outlet 16, to permit complete control of the level of the stock relative to the plates. The position of the plates being fixed, the use of the adjustable dam board 32 allows the operator to back up the water and stock under the plates until the screening action is satisfactory. If the stock level is too high, the diaphragm will shoot the stock back through the plates; if the level is too low, the capacity of the screen is decreased, as there must be enough surge to keep fibers from settling thickly on the slots. The operator should adjust the dam as he looks down on the screen, while the screen is in operation. Sometimes a variation in the sizes of the slots in the different plates is successfully used to increase the capacity of a screen. When this is done, the oncoming stock is forced to follow a definite path, mapped out with baffles. The plates having the larger slots are near the receiving end, where the stock flows freely and rapidly; the plates having the smaller slots are at the other end, where the flow of the stock is retarded and the stock has nearly finished its journey. Stock is nearly always delivered to a screen at one end, there being a slight slope downward of the plate surface to the other end.

Screen showers are important on flat screens to keep the stock in motion and the screens clean. These showers should carry a medium pressure and be directed at an angle, so the shower water will be discharged with the movement or flow of the stock, instead of straight down or against the flow.

Screens should always be kept clean; otherwise, they soon become filled with stock. This not only decreases the capacity of the screen but it also increases the danger of accumulating lumps of stock. In time, these lumps get into the flow-box 11,

Fig. 18, from which they find their way to the paper machine, and are a frequent cause of breaks.

30. Care of Screens.—The screens should be well washed at least once a week, preferably with a high-pressure hose and hot water. This means that the boxes must be lifted out, the slots cleaned, and the interior of the diaphragms and all inner parts of the screen boxes thoroughly cleaned of all slime and traces of old stock, to prevent any accumulations of stock that will get on the wire and cause many breaks. The slime that collects in the screens forms a transparent spot in the paper, which will generally become a hole somewhere on the machine. These slime spots are a sign of dirty screens. Care should be taken that the screen diaphragms work right, that the outlet dams are properly adjusted, and that the hardwood blocks do not ride.

The use of a shower of water to wash the large slivers, shives, and dirt to the lower end of the screen is preferable to, and generally quite as satisfactory as, the use of scrapers. If scrapers are used, they should be made of softer material than the metal of the screen plates. The plates should be carefully handled and cleaned; and, if the slots are enlarged by reason of excessive cleaning, the plates should be discarded. Screen-plate manufacturers can recut old plates to some standard slot size. The screws must fit in the spacer pieces and sills, so each screen plate may be rigidly held in its place. It is almost impossible to keep screwed screen plates in condition after the sill screw holes get worn; in any case, there is a tendency for small screws to get lost or badly strained when the screens are cleaned. There are many designs of screwless screen plates, which are fastened in place by beveled or rabbeted cleats that fit specially edged screen plates. If not too complicated, all such designs are superior to the screw type.

Care should be taken to screw or clamp securely to the screen frame the top box that carries the plates, using a good watertight packing. The diaphragm screen is still very commonly used, in spite of many obvious drawbacks.

31. Rotary Screens.—A majority of modern paper mills use rotary screens because, with this type, it is possible to keep the screen plates continuously clean by means of a good shower. Rotary screens of simple designs and heavy construction, quali-

fied to give large capacity and long service, are available for any type of stock or service. They are of two general types; namely, the inward-flow screen, and the outward-flow screen. Both have their own peculiar method of agitating the stock, to assist it in flowing through the plates and in preventing the settling of fiber.

The *inward-flow type* of rotary screen is naturally of greater capacity than the outward-flow type, and it is best adapted to screening dirty stock. It is used for newsprint, book, sulphite

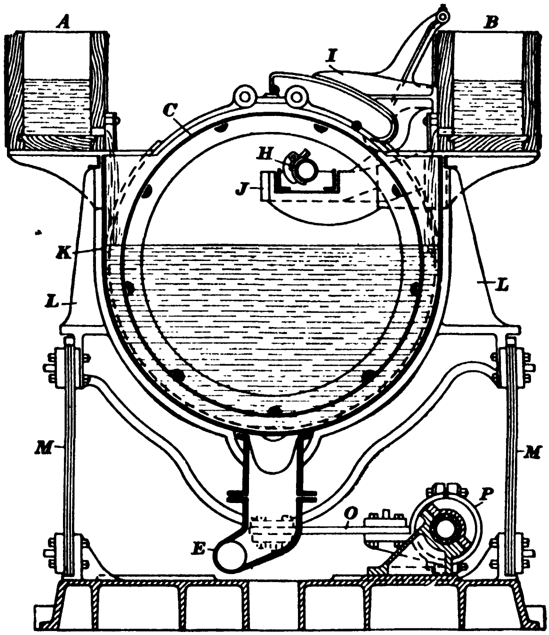


FIG. 19.

bonds, bag, wrapping, board, roofing, and coarse papers generally. The *outward flow screen* is better suited to the making of fine papers, such as ledgers, fine writings, and bond papers containing a large proportion of rag stock.

32. First Type of Inward-Flow Rotary Screen.—An end view of a frequently used **inward-flow rotary screen** is shown in Fig. 19. The stock enters through flow-boxes *A* and *B*, both being placed above the vat and discharging downward against a revolving cylinder *C*. The stock passes through the screens that form the shell of the cylinder; it then flows through an open journal, in

this case practically the end of the cylinder, to a discharge box or directly to the flow-box of the paper machine. There is a difference of level between the stock that is inside and that which is outside the cylinder. Stock that will not pass through the screens settles in drain *E*, from which it flows to the auxiliary screen. The latter is a specially designed, small, flat screen, where the good fibers are washed through and recovered. The slots in the revolving screen are cleaned by the shower pipe *H*. The pan *I* serves as a guard against splashing, and tray *J* catches some of the water that strikes the cylinder and falls back. The body of the vat *K* is made of copper plate; it is supported by two semicircular brackets *L*, which, in turn, are each supported by two vertical plate springs *M*. From the bottom of each bracket *L*, a shake arm *O* extends to the eccentrics *P*, which run at about 300 r.p.m. This vibration of the vat tends to churn the stock and urge the fibers through the slots. The cylinder is driven by a worm gear from the eccentric shaft, which may be connected by gears or a belt to a motor. A flexible rubber strip connects the fixed ends of the vat and the vibrating part.

33. Other Types.—There are several makes of screens in which the stock is agitated by means of immersed plates. In the screen shown in Fig. 20, the stock is agitated and assisted in flowing through the screen by two perforated steel plates *P*, which do not reach entirely up to the vat side; these plates are bent to the same radius as the screen cylinder *C*. The plates are hung, one on either side of the vat, playing between the vat wall and screening cylinder and extending the entire length of the cylinder. Each agitator plate is riveted to two steel suspension arms *A*, which reach from the lower part of the vat *V*, over the top, and back down the outside. A connection is made at *B* from the outside arm to the inside arm, near the lower end, by means of the connecting bolt, passing through a rubber diaphragm seal *D*. The agitator arms receive their pendulum motion through eccentric *E*, eccentric rod *F*, and rocker shaft *S*. The rocker shaft carries, perpendicular to its axis, an arm *G* on which the crosshead *H* rides, receiving its reciprocating motion from an eccentric rod. The arm carrying the crosshead is provided with an adjusting screw and hand wheel, so the location of the crosshead can be changed at will, thus imparting to the rocker shaft a greater or less

oscillating or rocking motion. Two short rocker castings *K*, keyed to the rocker shaft, transmit their motion by means of long connecting rods to the agitator arms on the opposite side of the vat.

In another type, a horizontal plate under the cylinder, and bent concentric with it, is vibrated up and down by an eccentric having an adjustable throw. Still another make has a plunger, with a

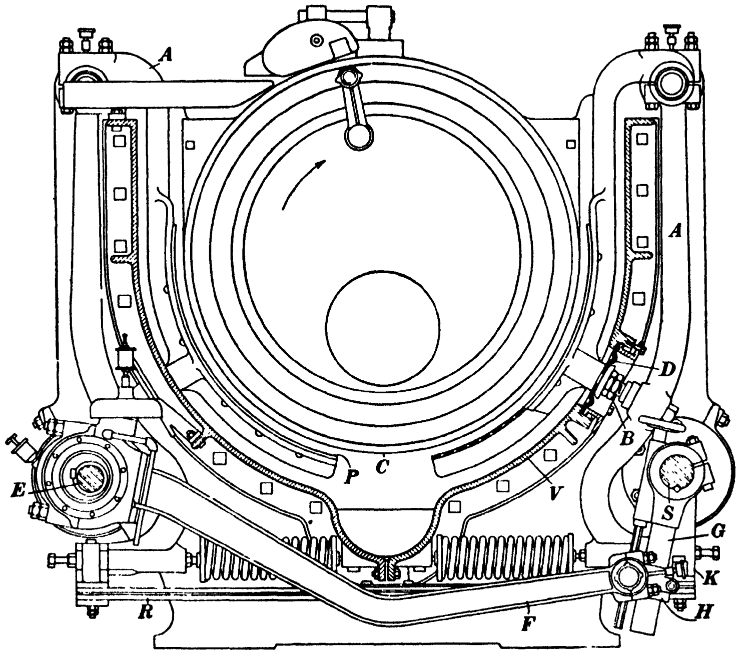


Fig. 20.

reciprocating motion, in a chamber below the screen; this creates suction alternately on either end of the screen cylinder.

34. Outward-Flow Screens.—A screen built especially to handle high-grade long-fibered stock is shown in principle in Fig. 21. It consists of a cast-iron vat and frames. The vat *N* is lined with copper, which prevents corrosion and the discoloration of the stock. The cylinder plates are made of specially rolled phosphor bronze. The cylinder heads are of cast brass, finished to offer a smooth surface to the stock. All fittings that come in contact with the stock are made of copper.

The stock is spouted into the cylinder A through a hollow journal at the end, into distributor M; it drops to the bottom of

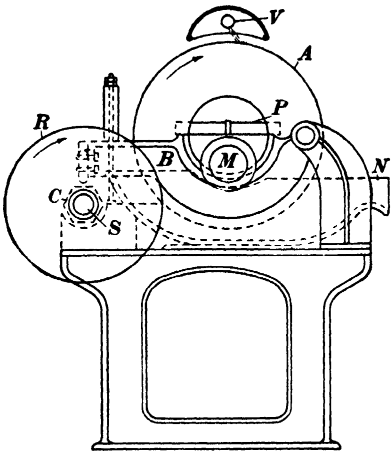


FIG. 21.

the cylinder, passes through the slots into the vat N, and thence to the paper machine. The rejections and impurities are carried up with the revolving cylinder, and are washed out through the discharge pan P by the shower V.

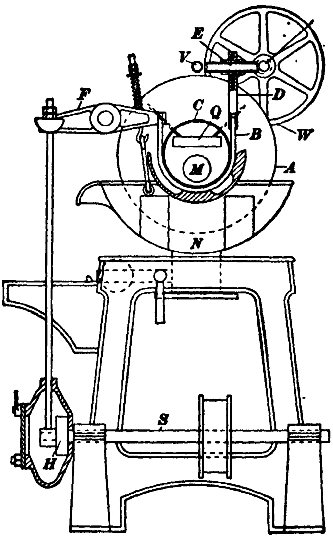


FIG. 22.

The camshaft S, with pulley R, and fitted with a six-pointed, round-faced cam C at either end, imparts an easy shake to the cylinder by the rapid lifting and lowering of the pivoted bearing arms B. This light but positive vibration (about 2000 strokes per minute) shakes out the massed fibers, and effectively puts them through the screen plates, well brushed out and ready for the paper machine.

35. Other Types.—Another example of the outward-flow screen is shown in Fig. 22. The stock enters the cylinder through pipe M at one end; it then drops to the bottom of the cylinder, passes through the slots into the trough N, from which it goes to the

paper machine. The rejections are carried up with the revolving cylinder *A* and are washed out through the discharge pan *Q* by the shower *V*. The shaft *S*, driven by eccentric *H*, is fitted with a lever *F* at either end; it jerks the straps *B*, on which rest circular projections *C* of the cylinder *A*, which would be journals if they turned in bearings. This jerking of the straps vibrates the cylinder, and it hitches it around at the same time.

In another mechanism, by means of which the screen itself is made to vibrate, the screen is carried on an arm which is pivoted at one end; to the other end is attached a pawl, which engages with an interrupted cam, or ratchet wheel. As the ratchet wheel revolves, the pawl is lifted; and this, in turn, lifts the arm and screen. When a point of the tooth is passed, the pawl, arm, and screen fall; this jars the screen, and the jar loosens any fiber that may have clogged in the screen. The screen is revolved by a ratchet wheel that is attached at one end of the cylinder.

A popular English screen dithers (vibrates) the cylinder by means of an adjustable rotary-eccentric center bearing at one end. The shaft, which makes 600 r.p.m., carries in an eccentric position a circular hub that turns in a Hoffman ball bearing, which is attached to the spider that supports one end of the cylinder.

36. Conclusion.—Outward-flow screens are thus seen to require that the screen cylinder be agitated to assist the flow; but with inward-flow screens, there are also available several other methods of agitating the stock. An outward-flow screen is cleaned by a shower pipe outside the cylinder.

The principal differences in rotary screens lie in ruggedness and simplicity of design, difference in the methods of creating suction and agitating stock, and the method of removing the rejected stock.

A very good discussion of screens is given in the Section on *Treatment of Pulp*, Vol. III.

THE MODERN PAPER MACHINE

ORIGIN AND DEVELOPMENT

37. Robert's Invention.—The process of making paper by hand—which was the method in universal use until the invention

of the paper machine by Louis Robert, in France, in 1799—is described in the Section on *Handmade Papers*, Vol. V. For both handmade and machine-made paper, the preparation of the stock is the same, and has been fully explained in previous Sections.

The first papermaking machine designed by Robert, see Fig. 23, consisted of an endless wire cloth *A*, which passed between two rolls *B* and *C*. The position of *B* was fixed, while *C* was adjustable, so the wire could be stretched. The beaten pulp in vat *D* was thrown up by a revolving fan *E* against the baffle plate *F*, which distributed the pulp and water in an even stream on the moving surface of the wire cloth. As the wire cloth *A* traveled slowly forward, the water passed through the wire, while the small squeeze rolls *G* completed the preliminary dewatering. The

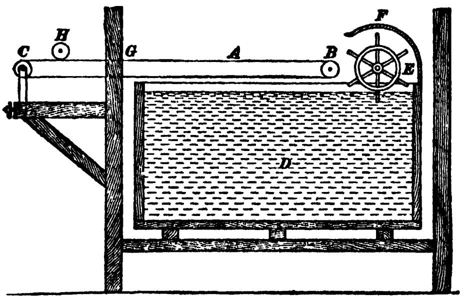


Fig. 23

receiving roll *H* reeled up the wet sheet until a sufficient length had been obtained, 50 feet being generally accepted as the practical limit. The roll was then removed, and the paper unwound, passed through some press rolls, and hung up to dry. A working model of this machine was made; but, as is always the case with a new design, it was not perfectly satisfactory. Robert was granted a bounty of 8000 francs to assist him in his studies and experiments; and he sold his interest in his patent and his model of the machine to his employer, Leger Didot, of Essones.

38. Early English Patents.—M. Didot realized the greater possibility of successfully perfecting such a machine in a country free from governmental strife, and, doubtless strongly urged thereto by his brother-in-law, John Gamble, an Englishman, he sailed for England in the summer of 1800. Didot had some mechanical ability, and it is possible that some improvements on the original machine were made by him before leaving France.

In England, he was fortunate in securing the help of Mr. Bryan Donkin, a man well qualified by his mechanical training to perfect the details of a machine of this type.

On Apr. 2, 1801, English patent No. 2487 was granted to John Gamble for the improved paper machine, the title of the patent being: "An invention for making paper in single sheets without seam or joining from one to twelve feet and upwards wide, and from one to forty-five feet and upwards in length."

Further improvement in design finally resulted in a new patent, No. 2708, dated June 7, 1803, issued by the English government to John Gamble for "Improvements and additions to a machine for making paper in single sheets without seam or joining from one to twelve feet and upwards wide and from one to fifty feet and upwards in length." In the autumn of the year 1803, the first papermaking machine ever to be built and successfully operated, was started in Frogmore, England; in 1804, another successful machine, practically a duplicate of the first, was put into service at Two Waters, England.

In 1804, Henry and Sealy Fourdrinier purchased the remaining interest of Didot and Gamble in the improved Robert machine. Henry Fourdrinier was granted patent No. 2951, on July 24, 1804, for "The method of making a machine for manufacturing paper of indefinite length, laid and wove with separate molds." On Aug. 14, 1807, an Act of the British Parliament gave an extension of the patent rights obtained by the Fourdriniers for invention of making paper by machinery. In this Act, the machine described by John Gamble in the specifications of his patents, Nos. 2487 and 2708, together with the added improvements, was all fully described and illustrated by diagrams.

During the year 1808, John Gamble assigned to Messrs. Fourdrinier all his rights in the patents as extended by this Act of Parliament, thus making them the sole proprietors of the patents covering the only successful papermaking machine in existence. So the machine invented by Robert, promoted by Didot and Gamble, designed by Donkin, and financed by the Fourdriniers came to be known, and continues to be known, as the Fourdrinier machine.

39. The Donkin Machine.—The first Donkin machine is illustrated in Fig. 24. The mixture of pulp and water, kept in a

state of agitation, flowed from the vat *A*, which is like a modern flow-box, through pipes and onto the endless wire cloth *B*, between the endless deckles *C*. The wet sheet of paper, having lost its excess of water, was passed between the squeeze or couch rolls *D*, as in the Robert machine, to be further dewatered; but, in this case, the work was better accomplished by reason of the traveling upper felt *E*. This felt, the ancestor of the couch-roll jacket, also improved the firmness of the wet paper. The paper then traveled to the press rolls *F* and *G*, and then was finally wound up on the reel *H*.

40. First Machines in America.—The first Fourdrinier machine in the United States appears to have been imported from England, in 1827, by H. Barclay, of Saugerties, N. Y. This machine was a Donkin machine, 60 inches in width. A second Fourdrinier machine, 62 inches wide, was installed in this mill

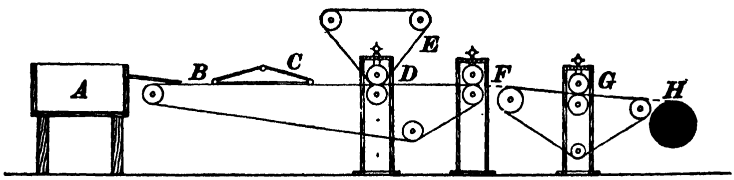


FIG. 24.

in 1829; but the second machine to be erected in the United States was imported from England and set up in the Pickering Mill, in Windham, Conn. This latter machine was copied by Phelps and Spafford, of Windham, and soon after that by Howe and Goddard, of Worcester, Mass. The Fourdrinier machine did not come into general use until several years after its first successful operation; even in England, only ten machines were made between 1803 and 1812, and only twenty-five more were built in the next decade. It was not until about 1830 that this great invention finally came into its own.

It is noteworthy that, in the early days, the cylinder machine patented by John Dickinson, in 1809, received more attention from mechanics and inventors in the United States than did the Fourdrinier. The supporting of the wire by table rolls in the Fourdriniers, and the use of these rolls in hastening the evacuation of the water, does not seem to have received the attention that these features merited; and, in so far as the writer

can find, no patents were issued covering these points. In fact, it is doubtful if many papermakers today realize to any greater extent than did the earlier generation the importance of the action of the table rolls.

41. Improvements in the Earlier Machines.—In 1826, Canson, in England, applied suction pumps to the Fourdrinier machine, to cause a suction underneath the wire on which the paper was formed, in order to assist in the removal of water. This invention really was an adaptation from the Dickinson cylinder machine.

It was not until the years 1889 and 1890 that the modern machine was perfected, which, with all its improvements, is essentially the same machine as the original of Fourdrinier and Donkin, with the addition of the cone drive and the steam-drying cylinders. Among the older papermakers, there still lingers the memory of when the paper dryers were headless cylinders, with a wood fire in each one. Steam cylinders for drying paper were first used by Crompton in England, in 1823.

The dandy roll was invented by J. Marshall, in 1826. In 1820, Barrett invented a method of making rolls true by grinding them together, using water and emery.

FOURDRINIER PART OF THE PAPER MACHINE

GENERAL DESCRIPTION

42. General Data.—A sketch of the wet end, or Fourdrinier-wire part of the modern paper machine is shown in Fig. 25. The flow-box, or headbox, 1 receives the stock from the screens. The stock goes through the slice 2 onto the wire 3, where a part of the water is removed by the table rolls 5, the flat suction boxes 6, and the couch press 9, 10 (or a suction roll). The sheet is then passed to the first wet, or woolen, felt, and then to the second and third felts, where additional water is removed by suction and pressure.

43. Course of the Wire.—The wire is suspended between the breast roll 4 and the couch roll 9, and is supported by the table rolls 5 in its travel down the machine. As it returns to the breast roll, it is supported and guided by the wire rolls 11, stretch roll 12, and guide roll 8. The last is sometimes located between the suction boxes 6 and the couch roll. The couch roll 9 is

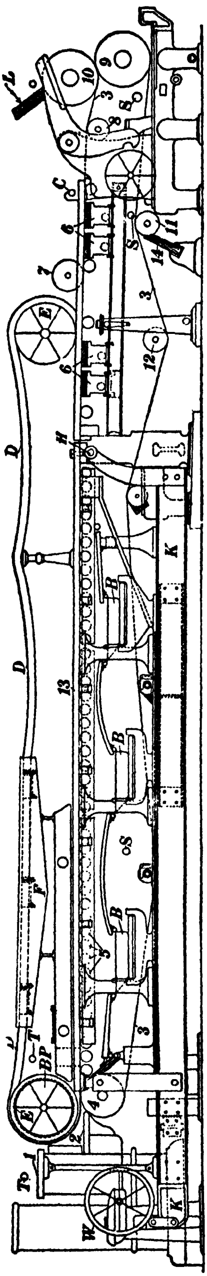


Fig. 25.

mechanically driven, and it controls the speed of the wire, which acts like a belt and drives the other rolls of the wire part. The dandy roll 7 runs on top of the sheet, and the stationary deckle board or deckle straps *D* are located at each edge of the wire to prevent the stock from flowing off the wire. The various rolls are supported by the frame of the machine, and modern or improved machines are usually equipped with special or antifriction bearings. Many machines have a shake, which consists of a lateral movement of the table rolls or a part of the wire section. The *shake* serves to create a leveling action of the stock on the wire, and tends to produce a mat or sheet with fibers crossed or interwoven in a horizontal plane, rather than on end or parallel to the direction of the wire.

As the water goes through the wire, it is usually caught in white-water trays or pans *B* and returned to be mixed with the new stock coming on the machine. In order to keep the wire clean and the meshes clear, wire showers *S* of either white or fresh water are provided at points on the return wire or on the wire rolls. Some of the wire rolls are also equipped with doctors 14, to keep them clean and prevent the stock from collecting on the inside of the wire and following back under the wire. The breast roll is equipped with a doctor, to prevent stock lumps or particles from getting between the breast roll and the wire; such an accumulation of fibers may wrinkle or damage the wire.

44. Principles of Sheet Formation.—The function of the headbox, slice, and apron is to deposit an even, smooth layer or film

of stock (fiber and water) on the rapidly moving Fourdrinier wire. The stock layer must be uniform in thickness across the wire, and the stock must flow on the wire at a speed equal to or a trifle slower than the speed of the wire. The embryo sheet of paper is then filtered or formed on the wire by the drainage of the excess water through the meshes of the wire, with the help of the table rolls and suction boxes.

The forming sheet should have a uniform distribution of fibers in the liquid; and, as these fibers are felting, they must arrange themselves in planes parallel to the plane of the wire, and also crosswise, lengthwise, and at various angles in order to produce a well interwoven mat of fibers. The design of the headbox, the type of slice, apron, table rolls, baffles, dandy roll, shake, and other mechanical equipment of the wet end, may have considerable influence on the formation of the sheet. The details

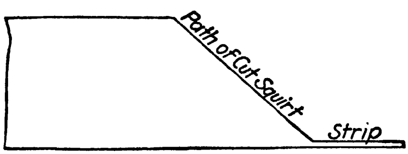


Fig. 26.

of the construction and operation of the wet end of the Fourdrinier machine are given later.

45. Transferring Paper from Wire to First Felt.—When the sheet is formed on the wire at the time of a start-up, or when a break occurs, the paper follows around the couch roll, and is knocked off the wire into the couch pit by means of a strong shower. The transfer of the sheet from the wire to the first felt is accomplished by cutting the wet sheet on the wire, between the flat boxes and couch roll, by means of a high-pressure jet of water, or *squirt*. A narrow ribbon or *lead strip* is first cut, and the machine tenders transfer this from the couch roll to the first-press felt. On modern and fast paper machines, this is usually done by means of an air jet inside the suction couch roll, which lifts the narrow lead strip (which is 2 to 4 inches wide) and blows it over onto the first felt. The squirt, which is attached to a traveling hose going across the wire, is then moved toward the back side, and the entire sheet is then cut, as illustrated in Fig. 26, and is carried on to the first press. If the machine has

no suction couch roll and air jet, the paper is lifted off the couch roll by the machine tender, who uses a wet wad of pulp; or in some cases, when the sheet is thick and the machine operates slowly, he can pick it off with his fingers. On a fast running machine, it requires great dexterity to transfer the paper by hand.

The squirt that cuts the lead strip and the sheet must have an adequate supply of high-pressure water, so the fine jet it throws down against the soft web of paper may not skip or cause a break in the sheet. The deckle squirts are usually tied in with the same high-pressure water system as the squirt of the paper machine.

The wet broke that goes into the couch pit is usually pumped back into the system again and re-used. It is necessary to remove all this paper stock that is carried around the wire; and if it is not taken off by the first shower directly behind the couch roll, it will be washed off by subsequent wire showers and doctors located at the various return-wire rolls. If any accumulation of stock should build up on the wire rolls on the top of the return wire and a lump of pulp should be carried in between the breast roll and the wire, it might produce a bulge in the wire, and spoil it. Hence, it is essential to have adequate showers to keep the wire clean and free from pulp as it returns from the couch to the breast roll.

46. Right- and Left-Handed Machines.—A paper machine is either a **right-hand** or a **left-hand machine.** If one stand at the dry, or calender, end and look toward the wet end, a right-hand machine will have the drive on the right side of the machine, while a left-hand machine will have the drive on the left side of the machine. It will be noticed that, on a right-hand machine, the machine tender lifts the paper from the wire to the first felt with his right hand; but he uses his left hand on a left-hand machine. The left side of a right-hand machine, or the right side of a left-hand machine, is called the *front,* or *tending side;* the other side is the *back side.*

DETAILS OF THE FOURDRINIER PART

FLOW-BOXES

47. Types of Flow-Box.—Various types of flow-boxes, or head-boxes, have been designed to meet the requirements of increased

speed of paper machines and the improvement in the quality of the paper. The function of the headbox is to receive the stock from the screens and keep the mixture sufficiently agitated to prevent flocculation of the fibers and, at the same time, steady the flow of stock so as to get a uniform delivery of the mixture at the slice. The height of the liquid in the headbox provides the hydrostatic head necessary to give the stock the requisite speed going on the wire. The simpler types used on slower machines are plain boxes or vats, through which the stock passes on its way to the slice and wire.

The more modern types, for higher speed machines and larger volumes of stock, are equipped with multiple passes, baffles of

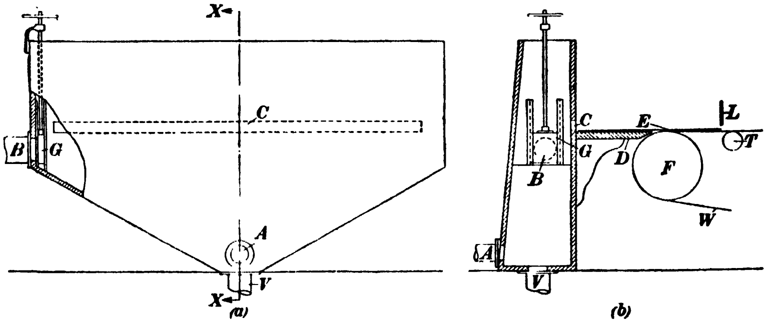


FIG. 27.

various types, flow eveners, and similar equipment, to direct and steady the stock to get more uniform delivery on the wire.

48. A Simple Flow-Box.—A simple flow-box of conventional design is shown in Fig. 27; it is similar in principle to those used on many of the older and slower running machines making high-grade or specialty papers. The stock enters at A, and as it fills the width of the box, its velocity diminishes. The stock rises in an even flow; it overflows at B, controlled by the gate G, into the white-water box, or to waste, until the machine tender is ready to start the wire. An opening V serves as a washout for cleaning.

49. Multiple-Pass Flow-Boxes.—On some machines, the flow-box has a series of *baffles*, shown diagrammatically in Fig. 28, to eliminate eddy currents. The stock enters at A, passes under the first baffle, over the second, through control and shutoff

gate C, and then onto the apron board D, through the slot at S. The edges of the baffles are rounded. Outlets V are provided at the bottom of each division, which discharge to the sewer, to the white-water tank, or to the pump intake; this takes care of the stock before the wire is started, and it prevents flooding the wire in case of a sudden shut-down.

On some machines, the stock enters at about A', and the first compartment is only as deep as shown at F; the next baffle then extends to the bottom of the box.

In Fig. 28, the slice S forms the front of a box, the bottom of which is the apron board D. In place of an apron, a brass plate,

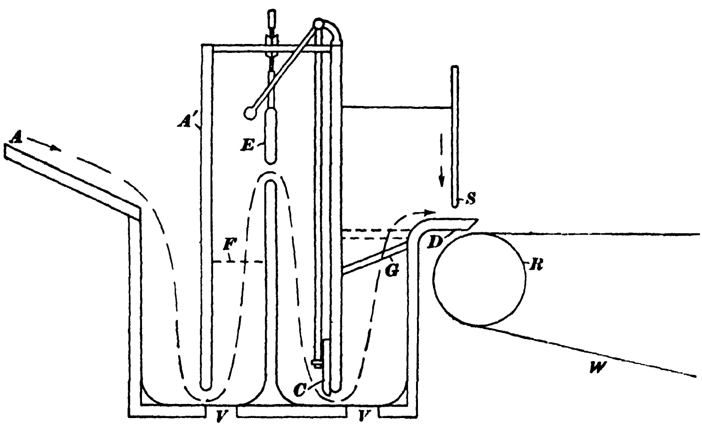


Fig. 28.

which forms the edge of the apron board, overhangs the breast roll as far as the top of the roll, and is about $\frac{1}{2}$ inch above the wire. The edge of the slice, which is sharp, comes about an inch behind the edge of the plate. Wood or metal grids G help to eliminate eddies and ripples. The deckle straps come back against the ends of this slice box, and they are held close to it by single-flange deckle-strap pulleys, Fig. 31. The slice plate is adjustable, to provide for two widths of the deckle; and the depth of the stock, which is the *head* in the slice box or pond, can be so adjusted as to control the velocity of emergence, and to make it accord with the speed of the wire.

50. Single-Pass Flow-Box.—A type of high headbox and slice, based on hydraulic principles and especially adapted to

high-speed machines, is shown in Fig. 29. The headbox *A* is made of wood, and evenness of flow is secured by means of the narrow 'eveners' *G*, set edgewise to the stream at close intervals across the paper machine. The oscillating rectifier, recently installed on some machines, consists of closely spaced, thin, stainless blades, with their vertical planes disposed parallel to the flow of the stock immediately before it leaves the slice. The rapid oscillation or vibration of these rectifier blades in a direction at right angles to the flow of the stock is said to be instrumental in obtaining more uniform distribution of stock across the wire, and better formation. The front of the flow-box is a heavy brass, bronze, or aluminum casting *C*, to the bottom of which is attached the flexible plate *S*, which forms the upper side of the nozzle orifice. The bottom face of the nozzle is a heavy plate *E*,

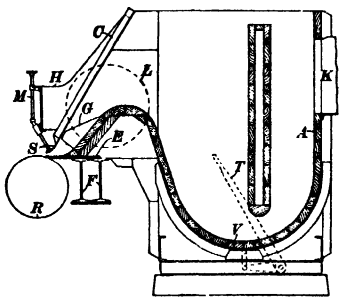


FIG. 29.

supported on I-beams *F*, and a thinner upper plate that extends almost to the top line of the breast roll *R*. The stock emerges parallel to the wire, and its velocity is determined by the head behind the slice. Uniformity of the thickness of the liquid across the wire is maintained by the adjusting screws *M*, which are carried by the brackets *H* on the front plate *C* and spaced about 6 inches apart across the paper machine. The position of the deckle-strap pulleys, which are carried by the side plates and form a part of the ends of the headbox, is shown at *L* in dotted lines. There are two washout valves *V*, operated by a handle *T* on the front of the machine. The stock inlet from the screens is at *K*.

THE PAPER-MACHINE SLICE

51. Purpose of the Slice.—Theoretically, the **slice** is a rectangular orifice or narrow opening across the width of the wire that permits the flow of the stock onto the wire in a sheet of liquid of even thickness or volume. The size of the slice opening, together with the consistency of the stock and the velocity of its flow, determines the thickness of the sheet of paper.

The older, or *conventional, slice bars* are used on slow-running machines where the head and the stock velocity are low. The bottom of the slice opening of the conventional type of slice usually consists of apron cloth dragging on the wire and attached to the headbox. On the high-speed slice, used on the more modern and higher-speed machines, the apron is not employed, and the bottom of the slice opening is a rigid *apron board.* Between the conventional and the high-speed types are a number

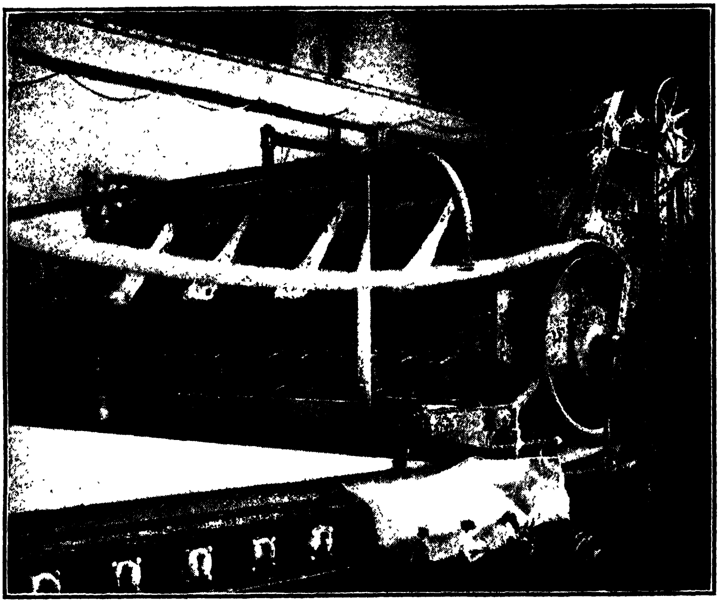


FIG. 30.—Headbox with flexible slice and deckle straps.

of variations, designed to suit the particular machine or grade of paper being manufactured.

52. Types of Slice.—The primary function of the slice is to deliver a sheet of liquid to the wire that will have the following characteristics: (*a*) uniform thickness across the wire; (*b*) a true directional flow with the travel of the wire; (*c*) maintenance of an equal stock velocity in every part of the slice opening.

Since the height of the stock in the headbox of high-speed news and kraft machines may be 60 inches or more, the problem of the high slice is hydraulic in character, though other factors may influence to some degree the projection of stock on the wire.

Modern types of slices are shown in Figs. 31 and 32; the latter is called an **inlet slice.** The principal difference in the two slices is the method of adjusting the lip. The one shown in Fig. 31 has flexible plates that permit adjustment of the long, narrow, horizontal orifice; the other, Fig. 32, has a hinged lip.

53. Relation between Slice and Breast Roll.—The high-head slice presents a rather complex problem in hydraulics, because of the shape of the orifice and because of the physical and other characteristics of the dilute stock. The relationship between the velocity of stock leaving the slice and the speed of the wire is one of the most important factors of sheet formation on medium-

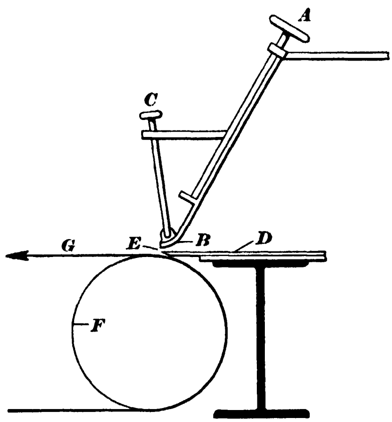


FIG. 31.—*A*, slice adjusting wheel; *B*, slice lip; *C*, lip-adjusting hand wheel; *D*, apron board; *E*, slice opening; *F*, breast roll; *G*, wire.

and high-speed machines. When the speed of the wire is at, or slightly greater than, the speed of the stock, the fibers are drawn in a horizontal plane and produce a well-formed sheet. If the stock speed is greater than that of the wire, the fibers will, in effect, 'stand on end,' or at right angles to the plane of the wire, and the result is a poorly formed sheet. Sometimes this action will be 'rolling' in effect, particularly on the heavier grades of paper.

The position of the breast roll is also important in sheet formation on high-speed machines. If it be too close to the lip of the slice, the velocity of the stock makes the major stream strike the wire beyond the breast roll, causing the wire to sag and the stock to throw upward when it strikes the first table roll.

The breast roll should be so located that the sheet of liquid being discharged from the slice will strike the breast roll just beyond the center line, so the initial weight of the stock will be borne by this roll rather than by the unsupported wire.

54. Conventional Slice.—The **conventional,** or **standard,** type of **slice** on old paper machines consists of two thin strips of metal

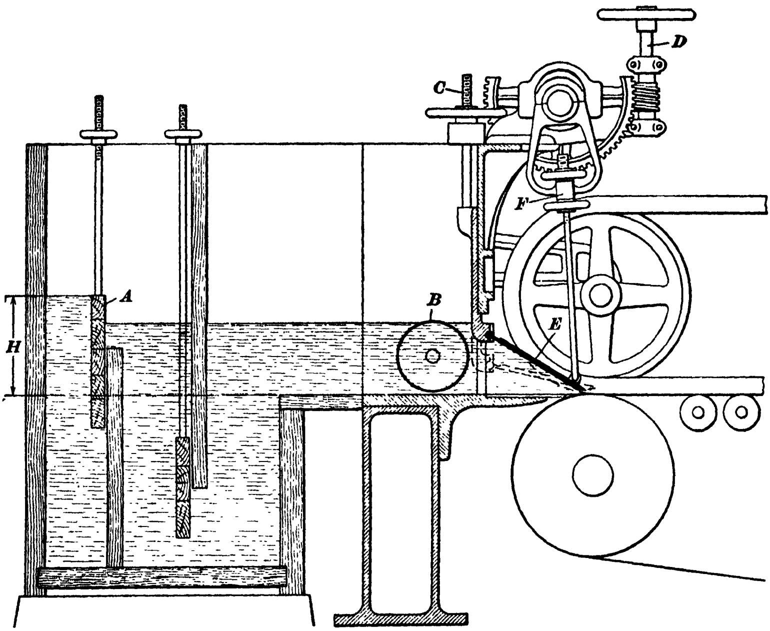


FIG. 32.—*A*, adjustable stock gate; *B*, perforated roll; *C*, adjustment for front plate; *D*, slice adjustment; *E*, hinged slice lip; *F*, adjustment for lip.

(or *slice bars*) across the wire, which permit the stock from the flow-box to go onto the wire as a liquid of uniform thickness. The slice is supported on the rails of the paper machine, and it is adjustable vertically to permit more or less stock to flow under the slice.

55. Double Straight Slice.—On many finer grades of paper, the **double slice** is used to maintain a more uniform flow of stock on the wire. The *pond* between the two slices is usually lower than the top level of the stock in the flow-box. The two slices are about 12 inches apart. Fig. 33 is a sketch, in perspective, showing this type of slice. The height of the slice opening with

respect to the wire is adjusted by means of the screws N; and when the proper height is obtained, the lock nuts L keep the slices stationary. The brackets B, supported and moved by the screws N, have T bars, which move up and down in slots riveted to the deckle frames A. The slices are made in two parts S_1 and S_2, to allow of sidewise adjustment; and they are joined and kept in line with each other by the adjusting screws K, which are held in clamps C, carried at the free end of either slice bar. When the deckle frames are moved in or out, as described in Art. **63,** the pinch screws P are loosened, so the slice will move

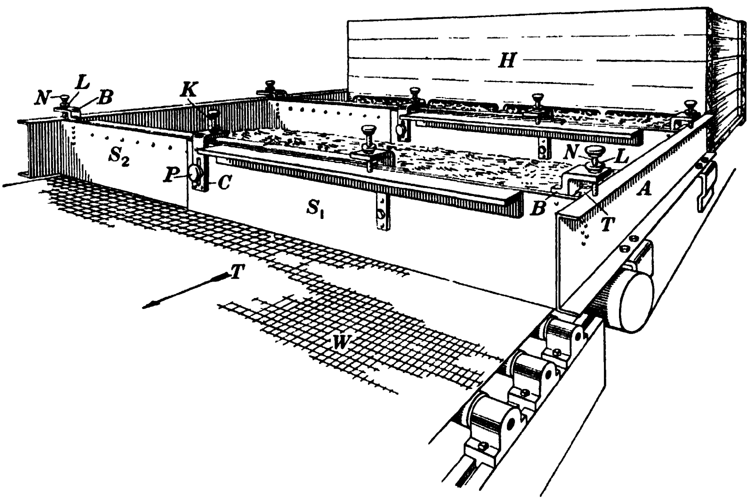


Fig. 33.

with the deckle frames. The pinch screws sometimes pass through horizontal slots in the slices. H is the headbox, W the wire, and arrow T shows direction of travel of the wire.

56. Position and Adjustment of Slice.—The lower edge of the slice bars must be kept straight and smooth, to prevent collection of any fibers. The lower edge must also be parallel to the wire, in order to maintain a uniform thickness in the stream of stock flowing onto the wire. Most satisfactory results are obtained by locating the slice just ahead or behind the center line of the table rolls. If the slice were located between two table rolls, a variation might occur because of a sag in the wire. On the other hand, if the slice is directly over a table roll and the table

roll is not properly balanced, or if it whips, there is a tendency to cause a streak in the sheet being formed on the wire.

57. Adjustable Straight Slice.—A variation of the straight slice is illustrated in Fig. 34; this is the so-called **flexible straight slice.** It is particularly suited for slower paper machines, with low heads on the pond. The slice S is placed at an angle, and can be adjusted across the sheet by the adjusting screws T, which are carried by a stiff plate P and located 6 to 12 inches apart along the length of the slice.

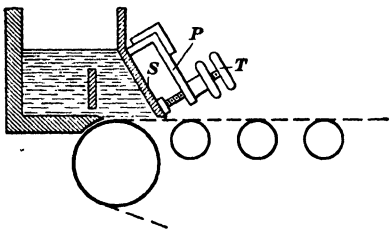


FIG. 34.

58. High-Head Slice.—The operation of paper machines at increased speeds has made it necessary to raise the height of the stock in the headbox, in order to get sufficient head to enable the stock to flow onto the wire at approximately the same speed that the wire is traveling. The so-called **high-head slice** has been generally adopted for high-speed newsprint, kraft, and other paper machines. There are two general types of this slice: one has a flexible lip that is curved at the point where the stock is discharged from the slice opening, as shown in Fig. 31; the other has a hinged flexible lip, with an adjustable front plate, as shown in Fig. 32. Both of these slices are equipped with individual adjusting screws to level the sheet across the wire, and, in addition, the entire wire can be adjusted up and down.

A recent development in slices on high-speed machines is the **nozzle type.** This slice has an upward sloping apron board, forming the bottom of the slice, and a flexible top section, with individual adjusting screws for sheet leveling. It is equipped with a series of baffles, or rectifiers, in the nozzle, where white water is also introduced.

Another variation of the high-head slice is the use of a rubber tip, instead of the curved flexible plate, which can be adjusted across the wire to obtain a level sheet on the wire.

Still another new principle of slice and stock feed to the wire is a forced pressure system that directs the required amount of liquid onto the wire at nearly right angles to the wire. High-

pressure stock pumps, or a high head of stock in the headbox, develop the correct hydraulic pressure to force the stock downward through the rectangular orifice and onto the wire at a speed about equal to that of the wire. One tissue machine so equipped operates at about 1500 ft. per min. The theory of this type of slice is that the primary, or initial, layer of stock forms or mats more uniformly on the wire, and that there is a smaller loss of fines through the wire. This slice is apparently better suited to a free stock, or to one made up in large part of chemical pulp.

59. Materials for Slices.—It is essential to have smooth and polished surfaces in contact with stock flowing at such high velocities. Chromium-plated materials, chrome-nickel steel, and other very smooth and non-corrosive types are preferred in making a satisfactory slice. Frictional variations, or minute projections at vital points in the slice opening, may easily disturb the flow of high-velocity stock and cause distortion of the sheet on the wire.

60. Adjustment of Slice.—The physical characteristics of the stock, such as freeness, temperature, percentage of fines, and other characteristics, have an important bearing on the height that the stock must be carried in the headbox for any particular grade of paper. Each machine usually presents a different set of conditions, since the speed, slope of the wire, and other operating conditions may be unlike those of another machine. In general, it is necessary to add sufficient 'water' to the sheet to carry it down to the dandy roll. This permits the stock to felt properly, and the sheet will be formed satisfactorily.

61. The Apron.—On paper machines making high-grade papers and equipped with the straight slice, it is necessary and customary to use the *apron* to bridge the gap between the *apron board* of the slice and the wire. This apron cloth is usually of such material as oilcloth, rubberized cloth, or light canvas. Sometimes a thin sheet of rubber is also used. The distance it extends down the wire varies with the different types of paper being made and the stock supplied to the machine.

THE DECKLE

62. Function of the Deckle.—The deckles are necessary to keep the stock on the wire and to form the edge of the sheet

going down the wire. The rubber deckle strap, supported by deckle pulleys at either end of the frame, is the conventional type of equipment on many paper machines. The same result is obtained with the **stationary deckle** or the so-called **no deckle** device, which is used on many modern machines making various types of paper.

63. Deckle and Frame.—The deckle parts are shown in Fig. 35. The deckle frame is supported on the rails of the Fourdrinier. The deckle pulleys *D* support the deckle strap *K,* which goes through a wash trough and is kept clean by scrapers. A shower of water is directed against the deckle strap, and clinging fibers are thereby removed.

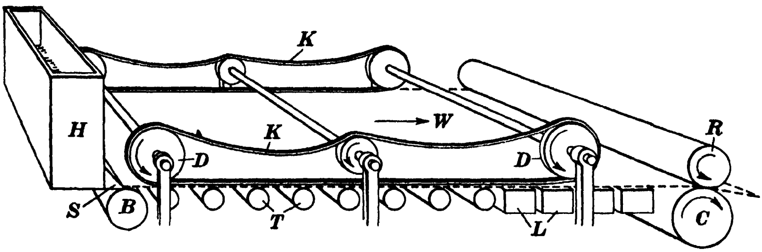


FIG. 35.—*H*, headbox; *S*, slice; *W*, wire carrying stock; *K*, deckle straps; *D*, deckle-strap pulleys; *B*, breast roll; *T*, table rolls; *L*, suction boxes; *C*, couch roll; *R*, rider roll.

Adjusting screws and gears are provided, so the deckle frames can be moved in or out a small distance when it is desired to change the width of the sheet. The deckle straps ride on the wire and travel at the same speed. Some deckles are supported from the machine foundation, in order to eliminate the necessity of shaking them; this reduces repairs to the deckle frame and parts, though the edge of the sheet may not be so uniform. However, this is of little consequence on most machines, since the thin edge is cut off by the squirt.

64. Stationary Deckle.—The **stationary deckle,** or **deckle board,** is a device that replaces the deckle straps, together with the pulleys, frame, and other deckle parts. Because of its simplicity it has been adopted in a majority of modern mills. The simpler types consist of a bevel-edged board, supported by brackets on the Fourdrinier frame, and set down close to the wire. Some have a rubber strip on the bottom edge resting lightly on

the wire. Another type, shown in Fig. 36, is made up of a metal frame *F*, at the bottom of which is clamped a rubber strip *R* resting at an angle on the wire. The adjusting screw *G* provides for the adjustment of pressure of the rubber strip on the wire, and it also changes the angle of the deckle.

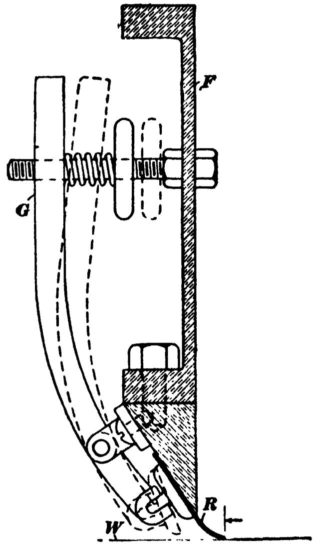


FIG. 36.

All these stationary deckles extend down the wire a distance sufficient to keep the stock on the wire until the water has been partially drained out of the sheet and it holds its position on the wire. Such a device is usually less than half the length of the ordinary deckle. The edge that the stationary deckle makes is not as straight as one made by the deckle strap, but this makes little difference in most papers, since the thin edges of the sheet are always cut off by the squirts. These deckle boards can usually be moved in and out to change the width of the sheet, and this adjustment is very easily made while in operation. A cleaning shower is often used on this deckle board to keep it free from lumps and stock accumulations.

THE SHAKE

65. The Shake and Its Function.—The Fourdrinier **shake** is the device that creates a series of short, quick movements of the wire at right angles to the machine direction of the wire. The *conventional shake* is so constructed that the breast-roll end of the Fourdrinier part has the greatest crosswise movement and the lower end has no movement at all. This shaking motion agitates and levels the sheet on the wire when it is in its most fluid condition, just after the stock leaves the slice. The shake is an important factor in forming the sheet on the wire, particularly in making the finer grades of paper, since the stock flowing onto the wire may not be absolutely uniform in thickness across its entire width. Another function of this cross movement is to

help distribute and mat the pulp fibers in a plane parallel with the top of the wire.

The interweaving of fibers by the shake is partly due to carefully adjusting the speed of the stock to the speed of the wire. The most carefully felted sheets are secured when the fibers settle by gravity as the water drains away; the fibers then fall naturally and evenly in all directions. The effect of the shake is to keep the fibers well mingled, while the forward travel of the wire tends to keep them parallel with the stock stream. The

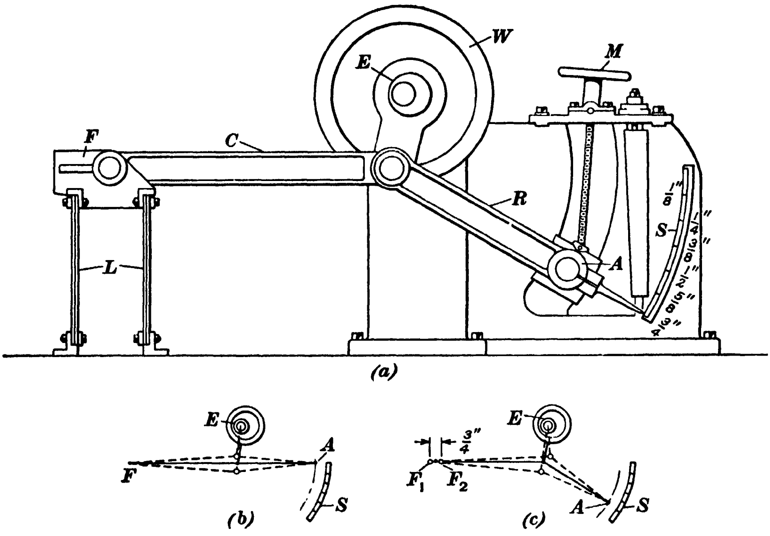


FIG. 37.

shake can be varied from a long, slow motion to a short, jerky motion; as a rule, the more violent the shake the better the paper.

The shake is not generally used on high-speed newsprint and on some other grades of paper, although a few machines have installed this type of equipment with a considerable measure of success.

66. Operation of Shake.—Several different types of shake arrangement are in use, a common type being shown in Fig. 37. The cross movement, or shake, is produced by the eccentric E and flywheel W, driven by a motor and speed reducer. The length of the shake may vary from nothing to $\frac{5}{8}$ inch, and can be adjusted by moving the sliding shoe device A and changing the

position of the fulcrum of the shake regulating link *R*. The connecting arm *C* is tied in with the Fourdrinier frame *F*, and it transmits the lateral movement to the frame of the machine. The crosshead *F* is supported on leaf springs *L*. The number of vibrations per minute can also be adjusted by varying the speed of the motor, or by other means. A shake of this type can be adjusted while in operation by movement of the linkage *R*, and the scale *S* indicates the amount of movement. The shoe is moved by adjustment wheel *M*. View (*b*) shows the position of the shoe *A* for no motion of the frame *F*, and view (*c*) shows its position for the maximum motion of the frame.

Other types shake the breast roll and some of the table rolls, or sections of the table rolls, or through other mechanical variations. The most important feature of any shake is to provide means to make adjustments to both the length of the stroke and the number of strokes per minute, in order to obtain optimum results on various grades of paper and at different speeds of the paper machine. A change in the character of the stock might require an adjustment in the shake to help in obtaining a proper felting of the sheet as it travels down the wire. There is no set rule for shake operation; the problem confronting the paper-maker is to get the best formation in the particular sheet of paper being made.

FOURDRINIER ROLLS

67. Types of Rolls.—As previously stated, the wire is supported by the breast roll and table rolls; it is driven or pulled around by the couch and is kept on the machine by the guide roll. The return-wire rolls and the stretch rolls are on the other side of the wire. The older machines also have a top couch roll. The felts have carrying rolls, stretch rolls, and guide rolls, as well as the top and bottom press rolls.

68. Stresses in Rolls.—The rolls are made of various materials, as wood, bronze, steel, cast iron, composition, and stone. They all tend to sag in the middle because of their weight, even when carrying no load. In addition to their own weight, the table rolls support a part of the weight of the wire and a part of the weight of the stock from deckle to deckle. Press-felt rolls are subjected to the pull of the felt, and sometimes there is half a

lap of felt on a roll and a double pull, while at other times there is very little lap and a consequent small pull. On some felts, the direction of pull is upward, and sometimes it is downward. The bottom press rolls have top press rolls resting on them, and the top press rolls have levers and weights on their journals, which increase the pressure of the top press roll on the felt and bottom roll. That the machine may make a uniform sheet of paper, it is advisable that the top of a bottom roll be always *straight* as it turns over, and the top rolls should be straight across the bottom rolls.

69. Crown of Rolls.—In order to keep the sheet of paper uniform, it is necessary to **crown** a single roll, or the lower roll of a pair, by making its diameter in the middle just enough larger than at the ends to make up for the sag in the middle caused by the weight the roll carries when in the machine; the crown is measured in thousandths of an inch.

70. The Breast Roll.—The **breast roll** should not be crowned, because the wire wraps around a large part of its circumference, and if the roll were crowned, the wire would be stretched in the middle more than at the ends, thus making the center of the wire travel ahead. This not only would shorten the life of the wire but it would also tend to give an uneven surface on the table.

71. Breast-Roll Details.—The fact that the breast roll is driven by the wire makes it necessary, in order to lengthen the life of the expensive wires, that this roll should turn easily. It should be as light as possible; it should also be fairly large in diameter, so that the wire may turn it more easily, and thus reduce the strain on the wire that is due to bending the wire around the roll. For a roll to revolve easily, it should be *in balance;* it should be as light as possible, yet stiff enough to keep its shape; lastly, the journals should be well lubricated. In most of the modern machines of large size, ball or roller bearings are used on all Fourdrinier rolls of the paper machine; the starting load is thereby lowered, and this reduces the strain on the wires and clothing.[1]

The breast roll is not driven independently, because of the practical difficulty encountered in so driving the roll that its peripheral speed will exactly equal the speed of the wire, which is driven by the lower couch roll.

[1] Clothing is the name given to the combination of jackets, wet felts, and dryer felts.

Fig. 25 shows the breast roll 4 in place, with the doctor as it is usually arranged. The doctor scrapes off the pulp and keeps it from passing around with the roll, under the wire, which would cause stretching and damage to the wire. All breast rolls are ground straight, *i.e.*, without any crown.

Since the breast roll is on the wet part of the machine, it should be made of non-corrosive metal. It is also in position to pick

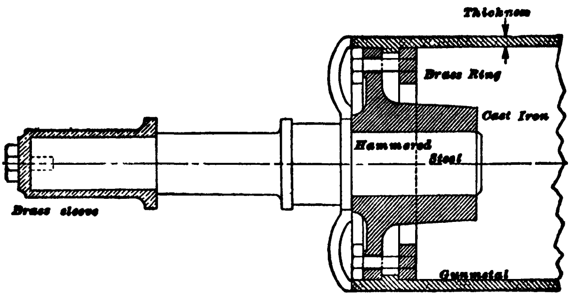


Fig. 38.

up much fiber, and it should therefore have a doctor to keep it clean. Some of the other rolls of the machine also require doctors or showers to keep them clean and free from an accumulation of fibers and lumps.

A sectional view of a breast roll is shown in Fig. 38. The design indicates that every effort has been made to make the roll

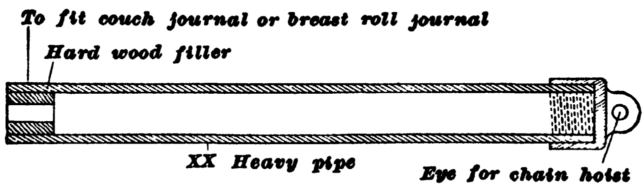


Fig. 39.

as light as possible. The extension with the brass sleeve is provided for the purpose of slipping the end of a *lifting lever*, or *porter bar*, see Fig. 39, over the end of the journal, as the breast roll is being lifted out of the machine when changing wires.

72. Table Rolls.—A table roll is shown in Fig. 40; it consists of a steel tube, cast-iron heads, and steel journals. This type of roll, covered with a brass tube or casing, is a standard design of

Fourdrinier table roll. The illustration shows the general construction of stretch, guide, and wire rolls.

The table rolls must be as light as possible, consistent with the securing of necessary stiffness. They are made from a brass tube *T*, and have a cast-iron or brass head *H*, which carries the steel journal *J*. Some table rolls are made of aluminum or other light weight non-corrosive metals; other rolls are rubber covered. The journals rest in adjustable bearings that are supported by the shake rails, either on the rails or under them.

73. Size of Table Rolls.—Fourdrinier rolls will soon deteriorate if acid stock is used. The acid attacks the zinc in the brass covering; and, in course of time, it leaves only a pitted, porous, copper shell, which might break. This action occurs in connection with all brass parts. The table rolls have the smallest diameter of any of the Fourdrinier rolls, varying from 2 inches in diameter on small machines to 6 inches, or larger, on the very

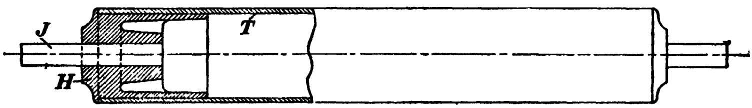


FIG. 40.

wide machines. Machine designers now recognize the advantages of large rolls.

74. Care of Table Rolls.—Care should be taken to keep the table rolls turning; if a roll is allowed to stop turning (become dead), it wears the wire, and the roll itself wears flat where the wire passes over it. When a roll having a flat spot on it turns, it jumps the wire and makes ridges in the paper. If after proper lubrication and adjustment a roll will not keep turning, it should either be replaced with a new roll or, if only slightly worn, the journals and bearings should be inspected and corrected. On high-speed machines, it is particularly important that all table rolls be in balance, and that the bearings (usually anti-friction) are accurate. If a table roll is out of round, the whipping action of this roll at high speeds will spoil the formation of the sheet, especially if it be near the breast roll.

In addition to reducing the friction between the table roll and the wire, the table roll must turn, to permit the moving surface to help remove the water from the paper more easily.

75. Effects Produced by Table Rolls.—The diagram, Fig. 41, illustrates how the swiftly turning rolls on high-speed machines tend to throw water back under the wire. The rolls have much the same effect in inducing water to leave the under side of the wire as is produced by touching the inside of a wet tent or a string of rain drops. A film of water may follow the roll to the wire and flow down the back side of the roll.

On some high-speed machines, baffles have been installed between the table rolls; these may be vertical or at a slight angle toward the breast roll, and are so located that they almost touch the under side of the wire. These baffles prevent the adjacent table roll from throwing the white water back and up against the bottom side of the wire, since this might produce poor formation of the sheet on the wire; it would also tend to reduce the drainage action.

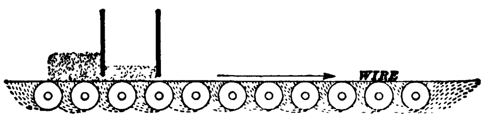


FIG. 41.

76. Effects of Water, and Its Removal.—It is necessary to carry sufficient water in the stock, or in the sheet, to keep the fibers in suspension for a considerable distance on the wire; this affords time for the fibers to interweave properly and produce a well-formed sheet. Since water drains rapidly from a free stock, such as is used for coarse papers, more water is then used to produce the required degree of suspension. High-grade papers are made from slow stock, and less water is required for these. Most of this water is removed as the paper passes the table rolls, more water is taken out by the flat suction boxes, an additional amount by the suction couch roll, and the last step in the mechanical removal of water from the sheet is by the presses.

The forming table, the suction boxes, and the suction couch roll must take out enough water to keep the paper from being *crushed* at the first press, which is the effect produced when water is pushed out unevenly, leaving the fiber in blotches, especially in thick papers. If the paper be too wet at the first suction box, the machine should be slowed down, less white water should be added at the regulating box, or the stock should be made more

free. The treatment in the beater should be changed to make the stock freer. If the forming table takes out the water too quickly, this method of handling the stock may be reversed.

When making tissue papers, the table rolls should be close enough together to keep the water that has been removed from being thrown back against the under side of the paper; a thin paper, such as cigarette paper, will be spoiled if drops are thrown against the under side of the wire. When starting a machine, it is well to begin with plenty of water, cutting it down gradually as more and more stock comes on. Starting with thick stock is liable to damage the wire should a lump run under the couch roll.

SUCTION BOXES

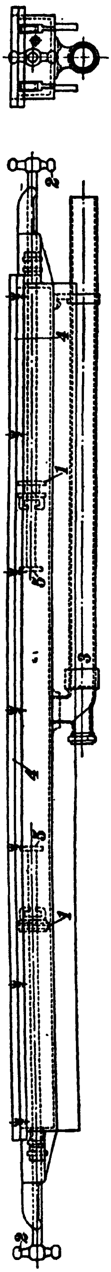


Fig. 42.

77. Purpose and Description.—The usual design of a suction box is shown in Fig. 42. The box is made of bronze, chrome-nickel steel, or other suitable materials, and its interior is rectangular in shape. The bottom of the box is connected to the suction pump by means of a pipe 3; in some designs there are as many as six outlets from the box to this pipe. The rubber pistons 1 are pushed in or are pulled out by means of the handles 2, the ends of which fit into slots in the pistons and lock them in position. The pistons are set just under the edge of the paper, to keep air from entering the box. On top of the box rests a perforated cover 4, made of hardwood (maple or mahogany) or, sometimes, of hard rubber, bakelite, or brass. Maple is preferable for suction boxes, since it can be easily planed and kept smooth, and the cover must be kept smooth in order to reduce the friction as the wire passes over it. The 'end grain' suction-box cover keeps smooth, and it wears a long time without planing or grinding the surface. The wire wears ridges or grooves in the cover, which soon destroy the mesh or cause the wire to wrinkle and

produce defects in the paper. If the stock is coarse and little suction is required, it is bad practice to close one box entirely; instead, reduce the suction on all the boxes, by slightly closing the valves on the vacuum-pump suction or by changing the suction relief.

From two to nine boxes are used, according to the kind of paper, speed of machine, and amount of water left in the stock after passing the table rolls. Many machines are equipped with an **oscillator,** which is a device for giving a reciprocating motion to one end, or both ends, of the suction boxes, so as to minimize the scoring of the box tops. Some oscillators have a double motion, and move up and down the wire as well as across it. The number of oscillations, or cross movements, varies between 10 and 40 per minute, depending on the grade of paper, the stock, and other operating factors.

78. Amount of Vacuum.—A vacuum gauge is usually placed on the suction-pump line from the suction boxes, so that the machine tender can be guided in his control of the suction. From 7 to 10 inches (mercury) of vacuum is ample for the suction; and if the work of the boxes is not satisfactory when over 7 inches of vacuum is shown on the gauge, it is better to place an additional box under the wire than to strain the wire too much by increasing the vacuum to above 10 inches. It is not unusual to see 14 inches of vacuum on the suction boxes; but this is bad practice, since the wires are then soon worn out. The suction pulls the wire down onto the top of the boxes, and tends to make the wire drag, like a brake. A vacuum of 7 inches on a 100-inch machine is equivalent to a load of about 700 pounds for each box. This increases the pull required to drag the wire across the boxes, and it also causes a suck-in and release as the wire passes, which strains the mesh. A patented arrangement minimizes this effect by placing the boxes contiguous. As previously stated, these strains on the wire should be made as small as possible, so as to save the wire and make good paper.

79. Vacuum Pumps.—There are three principal types of vacuum, or suction, pumps: (1) plunger pumps; (2) rotary pumps; (3) the gear type. The rotary and gear types are the ones used to a large extent at the present time. The old plunger type is used only for some special conditions, and is seldom employed in modern mills.

A section of one cylinder of a suction pump, which may have two or three cylinders, is shown in Fig. 43. The suction-pipe connection *S* is connected to the pipe 3, Fig. 42, of the suction boxes. Between it and the pump is a separator for taking out the air that is drawn through the paper as the water is removed. This

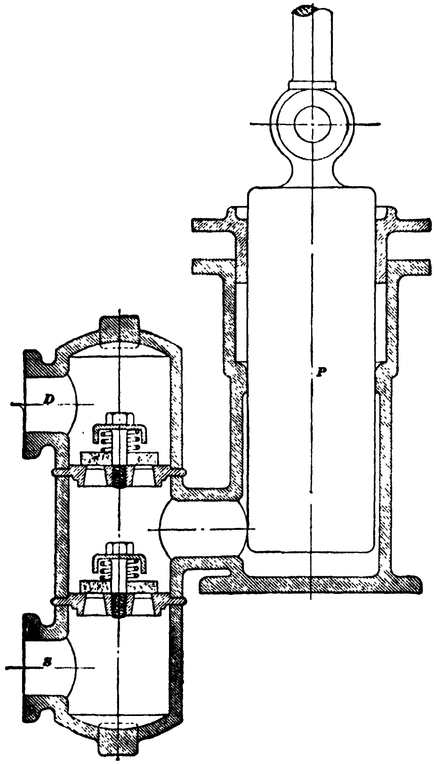


Fig. 43.

water contains recoverable fiber. The discharge pipe *D* delivers the water and fiber, sucked from the suction boxes. The action of the disk springs, as the plunger moves, is the same as that of the ball valves of the plunger pump. The spring insures quick and effective closing, with minimum leakage. In Fig. 43, the plunger *P* has just finished a down stroke; the air in the pump has been expelled through *D*, and the lower valve is about to open, as the up stroke of *P* admits air through *S*.

A section of a widely used rotary vacuum pump, in which water acts as a flexible piston, is shown in Fig. 44. (See Vol. IV, Section 8, Part 1.) This pump should not handle much water, unless it is equipped with an attached auxiliary rotor to remove the water. The rotary vacuum pump will handle a large volume of air, and it usually carries a vacuum of 18 to 20 inches.

Where there are large volumes of water going to the vacuum pump, a separator is usually placed in the line, as shown in Fig.

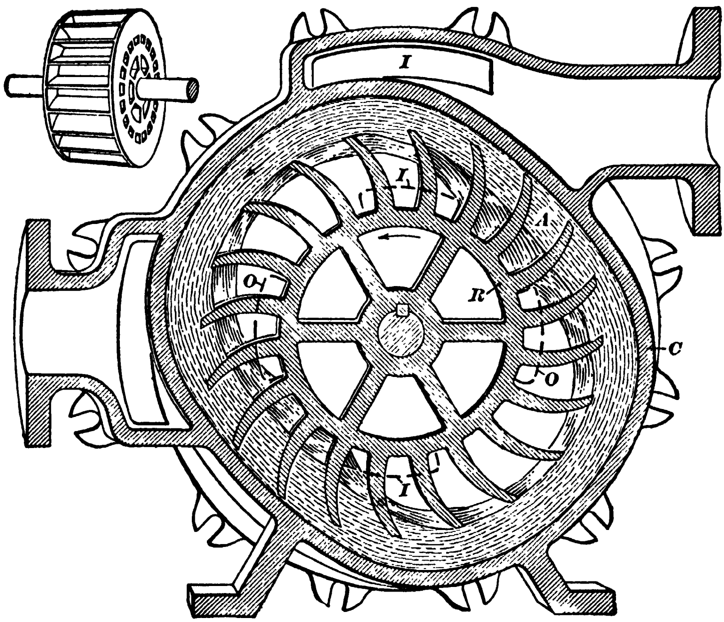


Fig. 44.

45. The water goes to the box *B* in the basement, which seals the 34-ft. deep water leg *W*, while the air goes to the pump *V* by the upper leg *A*. Suction boxes are indicated at *S*, and suction header at *H*.

Another type of vacuum pump that has been used to quite an extent in papermaking is shown in principle in Fig. 46. It consists of two parallel shafts connected with each other by spur gears outside the casing. This type does not require a separator in the line, since it will handle large quantities of water with the air. It is also used on vacuum filters. In operation, air is

drawn in at S and caught between the flat face of the rotor and the curved face of the casing as at F. The discharge is at D, when the shafts turn as indicated.

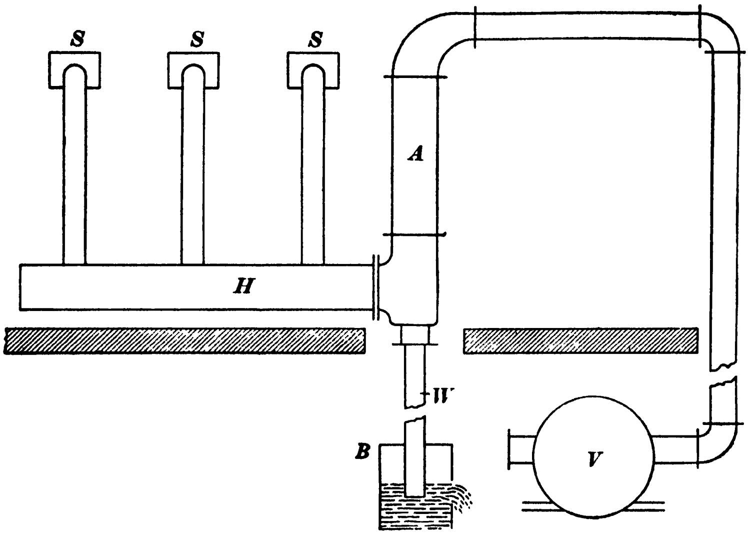


FIG. 45.

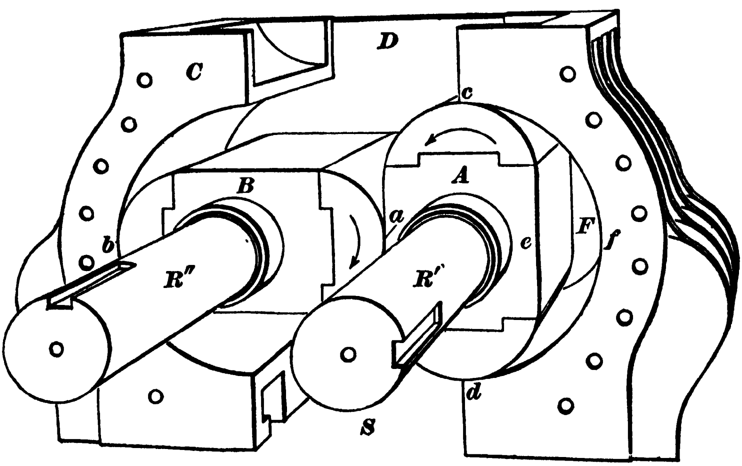


FIG. 46.

80. Displacement of Vacuum Pumps.—The amount of air and water removed by the vacuum pump varies greatly with the char-

acter of the stock and the operating conditions on the Fourdrinier. The vacuum on the suction couch roll is usually about 16 to 20 inches on high-speed newsprint machines, though it is possible to maintain a vacuum of about 24 inches. In order to keep the vacuum about 18 inches on a 3-roll news machine with a rotary pump, operating at speeds of about 1000 to 1200 ft. per min., it is necessary to have equipment that will remove 4000 to 5000 cu. ft. per min.

On high-speed machines, the first two or three flat suction boxes are on a water leg, and these remove a large volume of water. The remaining suction boxes are on the vacuum pump, which is sometimes a combination pump that will remove both air and water. An additional amount of water is then removed by the suction couch roll, and the sheet leaves the wire with a moisture content of 75 to 80 per cent, depending on the type of stock and the vacuum equipment.

The largest vacuum pump (Fig. 44) made for paper machines operates at about 190 r.p.m., direct connected to a 400 hp. synchronous motor, and rated at about 400 cu. ft. per min. This size is generally used on the suction couch roll of a 234-inch news machine. A smaller size, called a No. 9, runs at 277 r.p.m., and removes about 2000 cu. ft. per min. Various smaller sizes of vacuum pumps are used on smaller machines making different grades of paper.

GUIDING THE WIRE

81. Guide Rolls.—The **guide roll** is provided with a wire guide on the front side of the machine. A design of **wire guide,** as attached to the guide roll on a left-hand machine, is illustrated in Fig. 47. The guide acts by shifting the position of the bearings, carrying the front end of the roll forward or backward as the wire gets out of line.

82. The Wire Guide.—The guide roll gradually changes the position of the wire in operation, and the wire guide actuates the guide roll. The wire guide, Fig. 47, consists of a metal plate, or **palm** (sometimes called a *pan*), which is held in contact with the edge of the wire by a spring at all times. The palm is a vertical arm, which is attached by a series of levers to a double pawl, hung on an eccentric that moves up and down with each

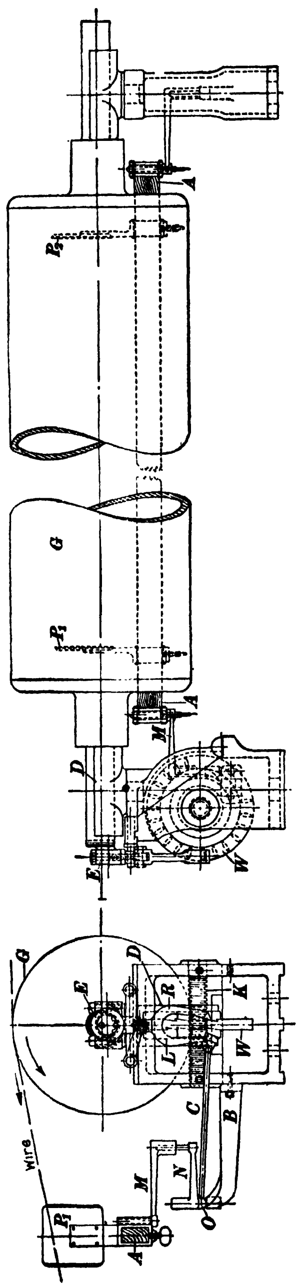


FIG. 47.—*A*, bar across machine to carry palms P_1P_2; *B*, bracket support for lever system *M*, *N*, *O*, *C*, transmitting movement of *A* to left and right pawl *L*, *R*; *E*, eccentric to raise and lower the pawl; *W*, ratchet wheel moved by pawl along screw *K*, and thus shifting bearing *D* of guide roll *G*.

revolution of the wire-guide roll. When the wire travels to the front (see Art. **46**) of the machine, it forces the palm outward. The lever arms move the pawl so that it engages the ratchet wheel, which is on a screw, causing the front side bearing of the guide roll to move up the wire and thus urge the wire back to its normal operating position. If the wire goes too far toward the back side of the machine, the opposite pawl is actuated through the palm and levers, the reverse action takes place, and the wire moves back to its regular operating position again. So long as the wire runs true on the Fourdrinier, there is no change in the position of the guide-roll bearing, although the pawl is in constant movement at each revolution of the roll, but without engaging the ratchet of the wheel.

THE DANDY ROLL

83. Size and Purpose of Dandy Rolls.—The diameter of a dandy roll varies from 7 to 24 inches, depending on the width and speed of the machine, the design of the watermark, and the kind of stock; it is placed on the wire and between the suction boxes (see 7, Fig. 25). The roll rests on the wire, and its journals re-

volve in guides rather than in bearings. It is turned by the friction between it and the paper. The dandy roll runs freely on the surface of the paper, with no pressure but its own weight. This, however, is sufficient to press out a little water; but its primary function is to flatten the top surface of the sheet, giving it a closer and smoother finish. The trunnion type of dandy roll is usually installed on newsprint machines, to improve the finish and formation, though not always considered essential. This type can be operated at speeds of 1300 ft. per min.

84. Wove and Laid Papers, and the Watermark.—If the paper is to be alike on both sides and without a watermark, the dandy roll is covered with fine wire, similar in texture to the machine wire. This dandy roll produces what is called **wove paper,** because the wire impressions are similar on both sides, and the paper has the appearance of being woven. A dandy roll that has a series of wires on its surface, the wires being so arranged as to produce *parallel* lines on the paper—these lines being more transparent than the rest of the paper—produces what is called **laid paper.**

When it is desired to make a **watermark** (a name or design) on the paper, it is effected by using a design on the dandy roll. A **dandy roll** is a skeleton roll, covered with wire cloth, upon which the design is worked in fine wire, though brass letters are sometimes used. This raised design makes the soft paper thinner where it comes in contact with the design, and the outline shows clearly when the paper is held between the eye and the light.

The circumference of a dandy roll is usually a little less than the distance (lengthwise) desired between the watermarks on the dried sheet, to allow for *stretch.* The distance crosswise between the designs is greater than is desired in the dried sheet, to allow for shrinkage. Dandy rolls for loft-dried papers should have a greater width between designs, because of the greater shrinkage in high-grade papers.

When the paper is to be cut so as to bring the mark in a definite place, as in the center of a letterhead, the stock must be kept very uniform.

85. Dandy-Roll Stands.—A dandy-roll stand is shown in Fig. 48. The stand is generally placed after the first set of suction boxes, but not directly over a roll. The illustration shows the

adjusting screws *S*, with a thumb head, and wing nut *W* for adjusting the height of the dandy-roll guides *B* to accord with the size of the dandy roll *D*. Lever *A* is so linked to the dandy-roll guides or bearings that an upward movement of the lever will immediately lift the dandy roll from the surface of the paper if, for any reason, it is necessary to do so. When not in use, as when starting the machine, the dandy roll may be hung on bracket *H*.

86. Trunnion Type.—The trunnion type of dandy roll is widely used on the newer high-speed kraft, newsprint, and other machines. This type of bearing makes possible the use of dandy rolls of larger diameter without increasing the weight out of

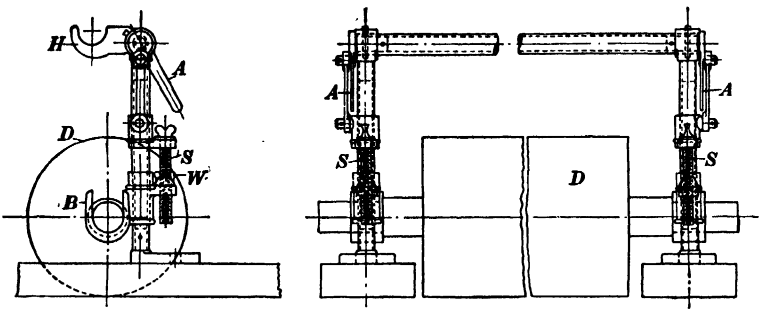


FIG. 48.

proportion to the size of the roll. The rim of the dandy is a typical trunnion that rests on two trunnion wheels, and is held in position by a third one. These three trunnions are on arms, and are spaced equidistant around the circumference of the rim of the dandy at either end.

When the dandy roll makes proper contact with the paper, a wet streak of even width shows just behind the roll. Experience is required to get the right amount of wetness to the paper so the dandy roll will make the correct impression. This is done by controlling the suction and the amount of water in the stock. The paper in this book is made with a wove dandy.

87. Defects Caused by Dandy Rolls.—**Dandy marks** sometimes cause defective paper and breaks. The wire cloth that covers the skeleton drum may become plugged in the meshes with fine particles of stock and filler; and when this occurs, the water on top of the sheet cannot penetrate through the plugged meshes.

As a consequence, at these points the sheet tends to stick to the face of the dandy roll, and a small piece is slightly picked up by the roll. This action makes a mark on the sheet that has somewhat the shape of a half moon. To remedy this, the dandy roll must be blown out with a steam hose, or else it must be taken from the machine and thoroughly washed out with water and steam. When the meshes are badly plugged, and the plugs are dried into the wire cloth, it may be necessary to use a steam hose. In some cases, dilute oil of vitriol (sulphuric acid), lightly applied with a cloth, is necessary to clear the dandy roll of these obstructions, and some mills keep steam, water, or air jets blowing through the dandy on the machine. A piece of wet felt, tacked to a bar, may be hung the length of the dandy for use as a wiper.

Unless very carefully cleaned at the end of a run, some paper stock will adhere to the wire, and the acid treatment will be required when the dandy is next used. The acid wash is prepared by pouring sulphuric acid into a pail of water in the proportion of 1 part acid to 5 parts of water. (Pour the acid into the water; it is dangerous to pour water into the acid.) The roll is placed on two supports (little horses); it is then scrubbed carefully, and is washed thoroughly with a hose.

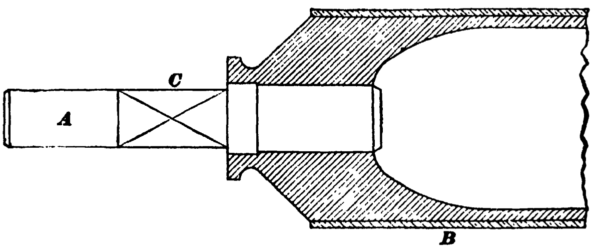
88. Placing and Removing Dandy Rolls.—In the modern mill, the dandy is lifted off and placed on the machine with a hoist or crane. The dandy bearings are lowered into the brackets, and the roll is given a spin in the direction of the paper travel as the dandy makes contact with the sheet on the wire. Some machines have a *walk* across the wire, supported from the frames, so the roll may be carried off; and they have brackets and levers for handling dandies.

COUCH ROLLS

89. Kinds of Couch Roll.—Until the development of the suction couch roll, all Fourdrinier machines were equipped with a *solid bottom couch roll* and a *jacketed top couch roll.* All machines recently installed have the *suction couch roll,* and this has eliminated the necessity of the top couch roll, which always caused many operating difficulties. In order to produce similar results in making the paper without a top couch roll, many machines are

equipped with a soft-rubber *riding roll*, which rests on the suction couch roll at the suction box. This helps to harden or solidify the wet sheet just before it goes to the first-press felt.

90. Purpose of Couch Rolls.—The function of the **couch** (pronounced *cooch*) **rolls** is to remove water from the formed paper and pack the fibers firmly together, so that the sheet is strong enough to pass to the first press. The top couch roll is couched toward the wet end; that is, it is not directly over the center of the lower couch roll, but bears somewhat on the wire. This arrangement permits water to be pressed out, and it causes the paper to be gradually squeezed between the wire and the felt



Width of Machine	100"	125"	150"	175"	200"
Diameter of Roll	20"	24"	26"	28"	30"

FIG. 49.

jacket on the upper roll before being finally squeezed between the two rolls. The couching action guards against crushing the paper, which occurs if the sheet be too full of water when entering the 'nip' between the two rolls; and water has a better chance to get away through the wire.

91. The Lower Couch Roll.—A section through a lower couch roll is shown in Fig. 49. The extension *A* provides room for the lifting pipe or porter bar, Fig. 39, to fit over; *C* is the journal, and *B* is a shell, made of bronze, gun metal, or brass. This is a driving roll, with a heavy load to carry, and must not be crowned.

As is the case with the breast roll, the lower couch roll is not crowned, because an increase in the diameter at the middle of the roll would tend to stretch the wire, or would make it travel more rapidly at the center, which would cause strains and partially close the mesh.

92. Driving the Couch Rolls.—The lower couch roll is driven, and it pulls the wire over the other rolls and the suction boxes. The tendency of the wire to slip on a smooth roll is sometimes counteracted by covering the roll with rubber. A grooved roll is sometimes used on light papers, and a felt-jacket-covered roll may be necessary to prevent the wire from marking the paper.

The upper couch roll is usually driven indirectly from the lower roll, and the lower roll drives the wire. The wire carries the soft sheet of paper, and the paper really drives the upper couch roll. The nature of this sheet of paper demands that very careful attention be given to the condition of the bearings, to lubrication, and to the setting of the upper roll with reference to the lower roll, as regards both their position and the pressure between the two rolls.

93. Crushing: Cause and Remedy.—Adjustment of the pressure between the couch rolls requires consideration of the wetness of the sheet, to prevent crushing of the sheet. **Crushing** is a blotchy appearance of paper; it is caused by a too rapid pressing out of water, which pushes the fibers into bunches.

Crushing is common with heavy papers. The remedy is to increase the freeness of the stock, use less water, increase the suction on the suction boxes, and relieve the pressure on the upper couch roll. A suction couch roll eliminates the major part of these operating difficulties, and hence it is being generally adopted on new installations. Many old Fourdriniers have been built over, and the suction couch roll installed.

94. Couch-Roll Housings.—The two bearings of the upper roll are carried by the swinging arms of **couch housings,** see Fig. 50, which shows diagrammatically two typical designs. View (*a*) shows a bevel pinion on shaft *S*, which is actuated by a hand wheel (not shown); this pinion turns the larger gear *A*, which acts as a rotary nut and pushes or pulls on the screw *B*, thus moving the coucher arm *L* around the pivot pin *P*. Fig. 50, (*b*), shows a worm *W* and worm wheel *G* instead of a bevel and pinion.

Referring to Fig. 50, all upper arms are provided with weights and levers, attached to hook *H*, for controlling the pressure between the rolls across the machine. This design is similar in all practical details to that used for any press, whether for a couch roll or for any press part situated farther up the machine. The

upper couch roll is covered with a felt jacket, to secure a dry sponge effect on the wet paper.

95. The Guard Board.—The **guard board** is so placed that it squeezes out of the upper couch-roll jacket much of the water that has been absorbed from the paper, and it scrapes off lumps of pulp that might go around and dent the wire. With the water is a certain amount of filler and fiber, which is washed out at the

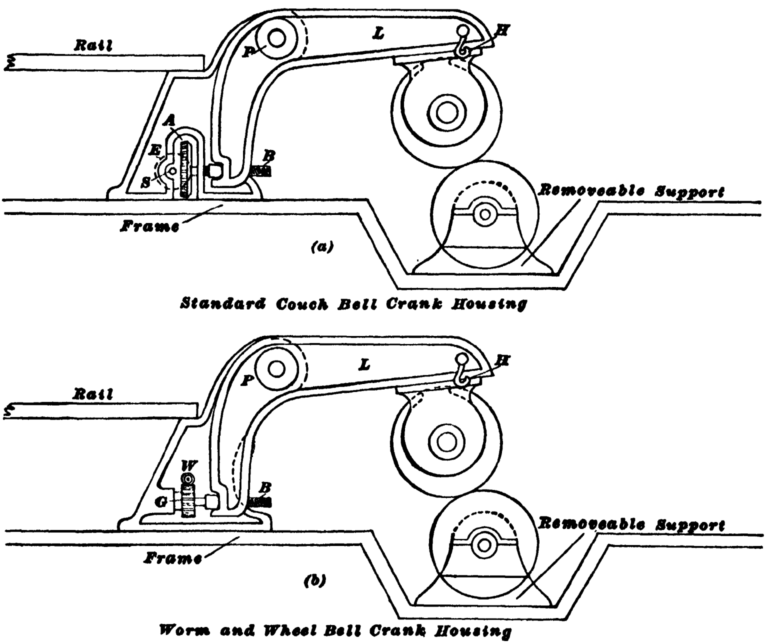


FIG. 50.

ends of the roll by the shower pipe *F*, Fig. 51. The guard board is set behind the center of the couch roll; this makes a little trough, which may be increased by a small roll *R* or by a felt wiper. Pipe *F* and roll *R* may be supported from the couch-roll housing.

The guard board should be adjustable, and it should have a flexible edge that can be adjusted to give a uniform pressure over the width of the jacket. Fig. 51 shows a typical guard board. A plank *E* is supported by cast-iron brackets, which are bolted to the top of the bell-crank arm of the housing. On the front of this plank, the light guard-board blade *D*, made of maple,

is held in place by a series of spring boxes H; through these boxes, double thumb screws pass, which are operated from above.

SUCTION ROLLS

96. Suction Couch Roll.—Many machines are equipped with a **suction couch roll,** and some have a **suction-press roll,** also; the former supplants the conventional top and bottom couch rolls, and the latter supplants the bottom roll of a pair of press rolls.

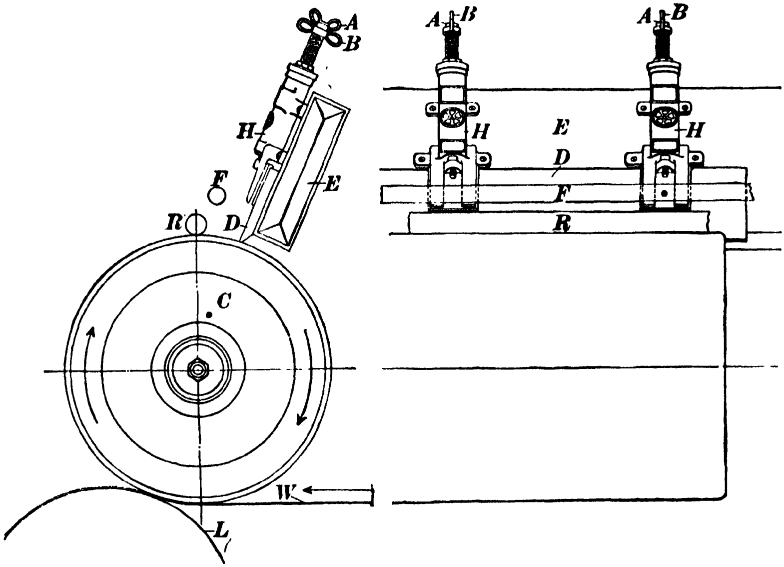


FIG. 51.

In principle, a partial vacuum is created in the roll, and atmospheric pressure, instead of roll pressure, packs the fibers and squeezes water from the paper. The vacuum, together with the large number of holes in the shell of the roll, permit rapid and uniform removal of water from the sheet.

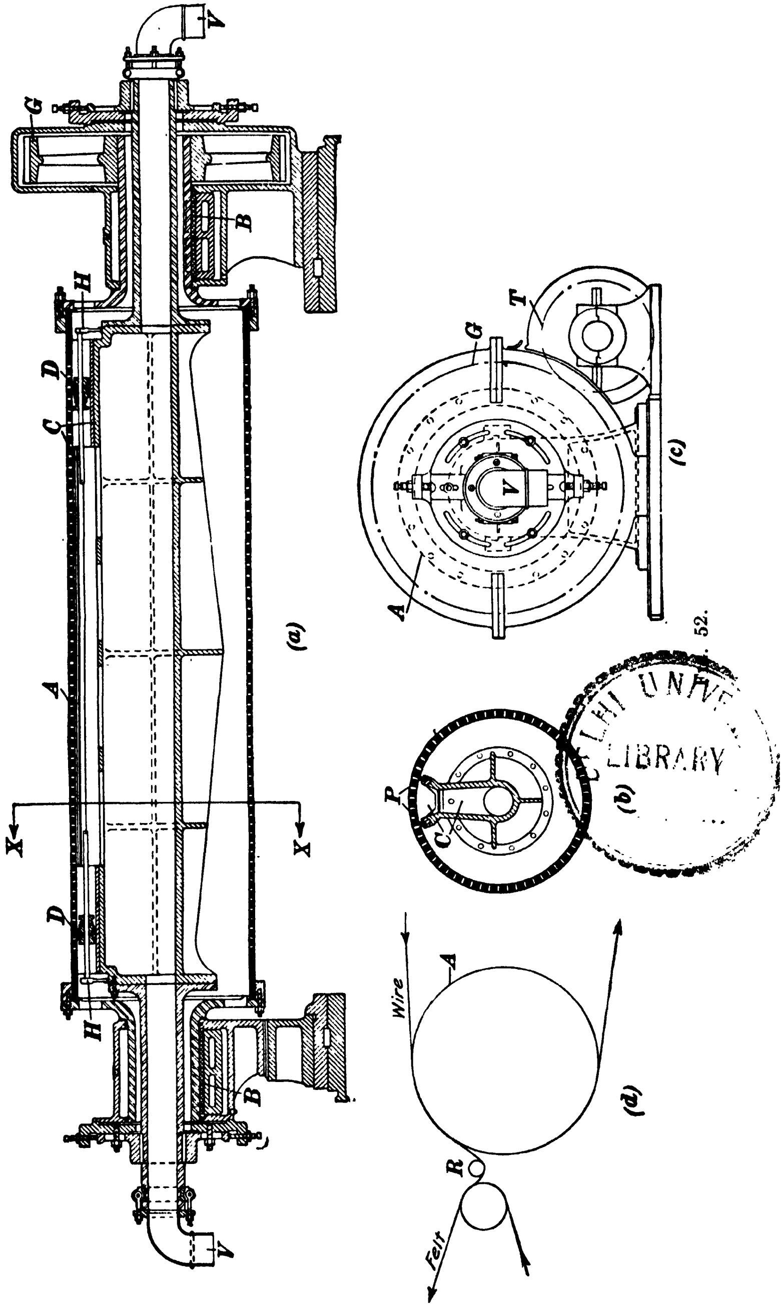
97. Construction and Installation.—The construction of the suction couch roll, and the method of its installation, is shown in Fig. 52. Here (*a*) is a longitudinal section, (*b*) is a cross section on the line XX, (*c*) is a right-end view, and (*d*) is a diagram showing wire and felt. A perforated bronze shell A is mounted in substantial bearings B; the diameter and thickness of the shell depend on the width, speed, and drag of the wire, and the best of

machine-shop work is required. The shell is revolved at the speed that is proper to drive the wire. *C* is the stationary suction chamber; it is connected to a powerful rotary vacuum pump. The pump is connected at *V*, and is usually located in the basement. Contact between the suction chamber and the inside surface of the revolving shell is made with special packing, which is held in place by springs and sealed with water. A piston arrangement *D*, operated by shaft and handle *H*, is provided on the roll, to adjust the length of the suction area to accommodate any width of sheet made on the machine. This piston fulfills the same purpose as the pistons on flat suction boxes. The chamber *C* need not be vertical; it may be swung back or forward. In view (*d*), the small roll *R* is a light aluminum roll, which is sometimes used to help maintain the proper draw of the sheet between the suction couch roll and the first wet felt.

98. Amount of Vacuum.—The degree of vacuum that can be maintained in the suction couch roll depends largely upon the weight and character of the paper made; about 15 inches of mercury is a fair average, being least on free stock and on thin paper. The shell *A* is driven by gear *G* from pinion *T*, shown in end view (*c*). Many suction couch rolls are direct driven by a motor on the back side of the machine, and the discharge of the suction box is at the front side. A suction couch roll requires more power for its operation than the ordinary pair of rolls. Since the shell is perforated, the usual strength formulas do not apply when designing these rolls.

99. Operation of Suction Rolls.—In order to understand the operation of the suction rolls, it must be borne in mind that, after the web of paper has been formed on the Fourdrinier wire, the essential remaining problem, insofar as the paper machine itself is concerned, is largely one of removing the water that is in the sheet; and this is accomplished by the suction boxes, the pressure of the couch and press rolls, and the evaporation. There are different ways in which the necessary pressure may be applied at the wet end. With present-day relatively high operating speeds, the water must be eliminated very rapidly from the newly formed and tender sheet.

100. Action of the Suction Couch Roll.—The suction couch roll eliminates entirely the necessity of the old top couch roll,



52.

with its felt jacket and guard board, both of which require considerable attention, and which are responsible directly for many of the troubles of the machine tender, such as crushing, pitch spots, wire marking, pickups, and accidents to wires. The avoidance of these troubles means greater production.

The suction couch roll does not displace the regular flat suction boxes on the wire; but the suction can usually be kept less, thus putting a smaller strain on the wire and giving it a longer life. Damp streaks are avoided, since the atmospheric pressure is uniform; the wires glide easily and run longer; and clearer watermarks are possible, when no top couch roll is used.

Suction couch rolls are in operation in machines running at speeds up to and above 1500 feet per minute, and the variation in the weight of papers being made is from 8 to 300 pounds.

101. Taking the Paper off the Wire.—When taking the paper off the wire, the sheet should be picked off the wire below the suction area. The paper will leave the wire more freely when using the suction couch roll than with the old couch rolls, provided it be taken off low enough to avoid the effect of suction.

On lightweight sheets and on machines operating at high speeds, a compressed-air nozzle blows the ribbon from the wire onto the first felt. If unusual difficulty be experienced with the draw, it may be caused by the felt suction box. This box is usually equipped with a vacuum regulator that can be weighted to change the degree of vacuum carried. As the vacuum increases, the paper will run down where it leaves the wire; and as the vacuum decreases, the draw tightens. If no draw roll, as *R* in Fig. 52, (*d*), is used, and the sheet is drawn too tight between the wire and the felt, the sheet will be strained; and, if it be allowed to run too slack, wrinkles may form and cause breaks.

The pistons *D*, Fig. 52, should be carefully adjusted to the width of the wet sheet. If the pistons are not out far enough, the edges of the sheet will run wet, and it is apt to wrinkle on the felt. Sometimes the edges will give a little trouble, if the deckle straps are worn and leaky or the squirts do not cut clean. If the pistons are put too far out, there will, of course, be an unnecessary reduction in the vacuum, because of the extra air being admitted.

102. Rubber Rider or Lump Rolls.—When the suction couch roll is used, lumps may cause a breakdown at the first press roll.

A rubber **rider or lump roll** is often run on top of the sheet, over the suction couch roll. This is a soft rubber-covered roll, of small diameter, and only heavy enough to squeeze the surplus water out of the lumps; it also has the tendency to close up the sheet and produce a higher vacuum. It is not adapted to all kinds of paper, however, but is in regular use on some newsprint machines.

A flat suction box on the first felt will help to lay the paper flat on the felt, and it will help to regulate the draw.

WIRE AND STRETCH ROLLS

103. Wire Rolls.—The Fourdrinier wire is in the form of an endless belt; it is supported by the table rolls on the upper Fourdrinier part and by the return-wire rolls on the under part, as illustrated in Fig. 25. These return-wire rolls are usually four or five in number; they are located in the best positions to give proper support to the wire and, at the same time, permit the wire to bear on the rolls sufficiently hard to help make the wire run true.

104. Stretch Rolls.—It is important to maintain the proper tension on the wire, since it is driven from the couch roll. The adjustment of the wire tension is made by the stretch roll, Fig. 25. Some large machines have two stretch rolls, though only one is provided on ordinary machines. This roll is equipped with a screw arrangement, usually operated by a hand wheel that moves the roll up or down, thus applying more or less pressure or tension on the wire.

105. Amount of Tension.—It is advisable to run the wire as slack or loose as possible, but it must be tight enough to prevent slipping on the couch roll. With the more general adoption of the suction couch roll, it has been necessary to operate with somewhat higher wire tensions, because the pressure, or 'bite,' is less with no top couch roll. The machine tender usually tightens up the wire with the stretch roll until it feels sufficiently taut. If the wire is true and has no slack spots in it, the tension required is at a minimum. If there are slack areas or edges in the wire, it is usually tightened up after running a few hours, in order to make the wire uniform throughout its entire length and across the machine. Undue tension may strain the wire in some part, or at a seam, and reduce its life of service.

Although some experiments and tests have been made on wire tension, there is no automatic tension device in common use. As the wire becomes older, it may stretch to some degree, and it may also become worn and smoother on the inside surface that is in contact with the couch roll. If this occurs, the wire should be tightened up to compensate for the stretch, and it is sometimes necessary to apply more tension on the older wire to prevent slipping on the couch roll.

106. Wire-Adjusting Device.—Some of the modern higher speed paper machines are so constructed that the position of the Fourdrinier wire at the slice can be altered to obtain the proper discharge of stock on the wire. In addition, many of the newer Fourdriniers are equipped with an elevating device that will raise or lower the wire part at the breast roll, and thus give the wire a greater *pitch*. The slice and headbox must also be changed to maintain the correct flow of stock on the wire. On high-speed machines, a normal amount of pitch for the wire makes it possible to form a sheet on the wire more satisfactorily and maintain better quality. It is not possible to establish a rule governing the best pitch for the wire, since this factor is only one of many that influence sheet formation. News machines are operating at speeds of 1000 to 1200 ft. per min. with both the flat wire and wires pitched as high as 30 to 36 inches, or nearly 1 inch per foot of wire (usually based on the distance between the center line of the breast roll and that of the couch roll). A normal pitch of about $\frac{1}{2}$ inch per foot of wire is considered satisfactory on high-speed machines.

On some of the large machines, the elevating device is usually operated by a hand-wheel and worm arrangement. The entire construction of this elevating equipment must be heavy, to take care of the operating conditions and, at the same time, maintain the wire part in proper adjustment.

FOURDRINIER WIRES

CONSTRUCTION

107. Selection and Materials.—A Fourdrinier wire must be strong, tough, and very flexible to stand the excessive wear and

constant flexing to which it is subjected in its travel around the breast roll, couch roll, and other rolls of the machine. Various alloys have been used in weaving this wire cloth, and a common one is composed of 80% copper and 20% zinc. The phosphor-bronze wire of 94% copper and 6% tin is also commonly used on modern high-speed machines. Monel metal, chrome-nickel, and other alloys have been used, but with little success.

The selection of a wire for any particular paper machine is generally dependent on the grade of paper being made and the characteristics of the paper machine itself. Most makes of wires are standardized as to the size of mesh, but are made to definite specifications for the width and length of the paper machine.

108. Mesh of Wire.—The number of wires or openings per inch of length designates the **mesh** of the wire. Wires for coarse papers, such as wrappings or news, ordinarily use the 60-mesh wire. Special groundwood book papers and regular book sheets require 70- to 80-mesh wire. There are some special papers, such as very fine tissues similar to cigarette papers, that require an even finer wire.

Several types of weaving are used by the manufacturers, and these give different characteristics to the wire. The standard weave is commonly used in many mills making bond, book, and high-grade papers. The *standard*, or *plain*, *weave wire* (cloth) is formed by interweaving the **shute** (crosswise or *weft*) wire over and under alternate **warp** (lengthwise) wires. The *long crimp wire* differs, in that the shute wire goes over two warp wires and under the third one. A *flat warp wire* has also been used in weaving Fourdrinier wires.

The long crimp wire is also made so the actual percentage of drainage through it will vary, due to the fact that the shute wires are closer together. This is particularly important on high-speed news and kraft machines, where there may be some change in the temperature of stock or in operating conditions at different times of the year. For instance, a 60-mesh long crimp wire may be of three or more different types; thus, 60 × 44, 60 × 42, 60 × 40, 60 × 38, the first number being the number of cross wires, shute wires, per inch of length, and the second the number of warp wires per inch of width. The standard that has been adopted for the regular plain-weave wire is:

Number of Mesh	Count of Mesh
55	55 × 38
60	60 × 40
65	65 × 44
70	70 × 52
75	75 × 56
80	80 × 60

The allowable variation in beats (shute wires) is plus or minus 2 per inch.

109. Wire Seams.—The Fourdrinier wire is woven into a flat cloth of the right width and length for the paper machine, and the two ends are seamed, making it an endless wire screen belt. The manner of making the seam has been a matter of much research and development by the wire manufacturers. Originally, the sewn seam was the only one available, and various types of sewings were adopted for particular grades of paper, in order to make the seam have the same characteristics as the rest of the wire. The most recent development has been the adoption of the brazed or welded seams, of which there are several types. The openness of the brazed or welded seam makes it more suitable for practically all grades of paper, and it will doubtless be universally adopted.

110. Drainage through the Wire.—The rapidity of drainage of the white water through the wire has considerable influence on sheet formation; the temperature and freeness are also important factors. However, the most suitable wire must be selected

Weave	Construction	Number of openings per square inch	Open area, per cent
Plain	59 × 38	2242	26.4
Plain	59 × 40	2360	26.4
Plain	65 × 44	2860	27.4
Plain	70 × 48	3360	26.7
Plain	70 × 52	3640	26.3
Plain	75 × 52	3900	25.6
Plain	80 × 56	4480	27.2
Plain	80 × 60	4800	26.8
Twill	59 × 38	2242	26.4
Twill	59 × 41	2419	25.9
Twill	70 × 48	3360	25.4
Twill	70 × 52	3640	25.2

for the grade of paper being made, after taking into consideration the characteristics of the stock and the operating conditions of the machine. The different types of wire construction give varying percentages of drainage areas, and the table at the bottom of page 82 records the amount of open area in wires of different mesh.

111. Drainage Time and Machine Speed.—The speed of the paper machine, as well as the stock and other operating factors, must also be taken into consideration when selecting a wire. As the modern machine has been speeded up, the time required to form the sheet has been definitely reduced; and this is more noticeable for such papers as newsprint, kraft, and similar grades. At the slower speeds and for higher grades of paper, the drainage and sheet formation are not so greatly affected by the type and construction of the wire. The following table indicates the amount of time available for forming the sheet on machines of different speeds and wire lengths:

Machine speed, ft. per min.	60-ft. wire		80-ft. wire	
	A	*B*	*C*	*D*
200	8.1	6.0	11.1	9.0
600	2.7	2.0	3.7	3.0
1000	1.6	1.2	2.2	1.8
1200	1.3	1.0	1.8	1.5

In this table, column *A* gives the time in seconds that it takes a point on the wire to travel from the breast roll to the couch roll, 27 ft.; column *B* the time to travel from breast roll to first suction box, 20 ft.; column *C* the time to travel from the breast roll to the couch roll, 37 ft.; column *D* the time to travel from the breast roll to the first suction box, 30 ft.

METHODS OF CHANGING A WIRE

112. Types of Fourdrinier Machine.—Since the Fourdrinier wire is in the form of a flat continuous belt, it must be installed on the Fourdrinier in such a manner that it is not bent, creased, or otherwise injured. It must finally be placed around both couch and breast rolls, with the table and wire rolls in their respective

working positions. In the older makes of paper machines, it is necessary to remove all the suction boxes, as well as the save-all pans and other equipment, before starting to put on the wire. The modern Fourdrinier machine has been made removable, so that the entire Fourdrinier part is moved into the aisle between the paper machines when putting on a wire.

113. Wire-Changing Equipment.—The narrow, old-type machine did not require much equipment to change a wire, only a few jacks, chain falls to lift the large rolls, and planks that were used to hold up the rolls as they were placed in their proper positions. The large modern machines, on account of the increased weight of rolls and other equipment, require power hoists and the electric crane to remove and replace the large rolls and other parts safely and easily. The traveling electric crane is a standard piece of equipment in the modern paper mill; it not only saves time and expense but also makes the job safer for both men and machinery.

114. Removing the Old Wire.—The old wire to be removed is cut off by making two small cuts in one edge of the wire, about an inch apart just back of the couch roll, and tearing out this strip of wire across the machine. The wooden reel on which the old wire is wound is put in place on the bearings located on the lower part of the Fourdrinier frame. The end of the wire near the couch roll is then started on the reel, the couch roll is started slowly, and the old wire is wound up on the reel.

115. Putting on Wire with Removable Fourdrinier.—There are two methods of stringing the wire when the machine is equipped with the removable Fourdrinier part. It may be 'strung' or suspended over the machine after the Fourdrinier part has been moved out into the aisle with a wire *dolly,* Fig. 53; or it may be strung in the aisle, and the Fourdrinier part moved into the wire. Fundamentally, these two methods of wire changing are the same, because the whole Fourdrinier part is moved into the wire that is looped up. When the wire is strung over the machine, it is necessary to slide the wire in around the couch roll; whereas the other method provides for the removal of the couch roll, as well as all the rest of the Fourdrinier part.

The following instructions together with Figs. 53 and 54 should make clear how the wire is installed on the removable Fourdrinier.

The wire bundle is placed in saddles mounted on trunnions in the wire carriage or supporting frame *A*, Fig. 53, and the

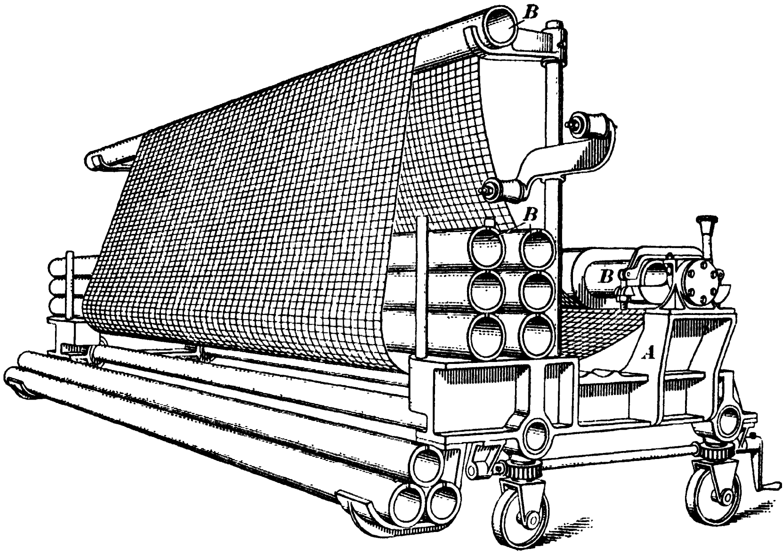


Fig. 53.

bundle remains in the carriage until the complete loop is formed. All the inside wire poles *B* are inserted in the carriage, then the

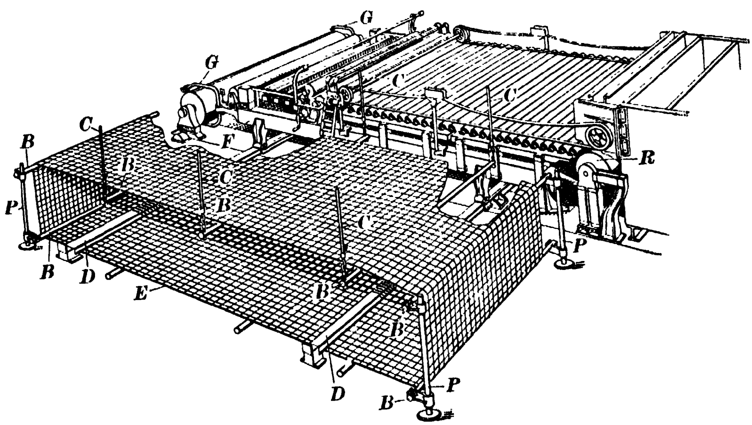


Fig. 54.—*A*, wire supporting frame; *B*, wire; *C*, remover beams; *D*, couch roll.

wire carriage is moved down the aisle, and as the loop is extended to the position shown in Fig. 54, inside wire poles are put into

place, supported by the overhead cables *C*. These cables are hung from the ceiling or a frame and are operated by a motor. The corner posts *P* of the wire-supporting frame extend down into sockets in the floor. After the wire loop *E* has been formed as shown in the sketch, the remover rails *D* are slid into position in the wire loop, the breast roll *R*, which is mounted on arms, is swung from its operating position to down and in under the Fourdrinier frame, then the Fourdrinier section *F* from the breast roll, to and including the guide roll, is run out into the loop. The Beloit suction couch is equipped with a cantilever jack on the rear journal. The front stand is equipped with a lightweight removable section held in place by hinged bolts. These hinged bolts are swung out of position, then a cantilever jack on the rear journal pushes the back journal down, which raises the front end of the suction roll and permits the hollow section to be removed to make room for the new wire. Deckle frame and straps, dandy roll, and other obstructing accessories above the frame are raised by overhead cables. The Fourdrinier frame is then run out on rails *D* into the loop of wire. The remover rails *D* are swung back out of the wire loop, the rollers resting on the pedestals in the aisle, the top wire poles are removed, allowing the wire to rest on the table rolls, and the bottom poles which rest on the floor are then mounted up under the Fourdrinier framework.

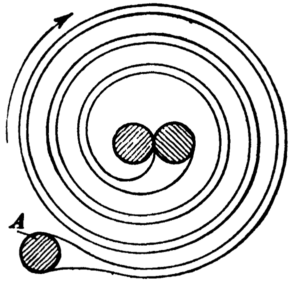
The yokes *G*, which are made of aluminum, shown over the suction couch are attached to the end of the Fourdrinier frames after the Fourdrinier section is inside the wire loop, and the end wire poles are shifted to the yoke position, which extends beyond the Fourdrinier framework, so that the Fourdrinier can be run back into the operating position, with the wire extended beyond the suction couch.

Then the remover rails *D* are swung back into position to permit the Fourdrinier section to be run back into its operating position over the wire pit. The yokes *G* and the bottom wire poles are removed, the breast roll is raised to its operating position, and the wire tightener is let down to take up the slack in the wire; the Fourdrinier is ready to go into production.

When the wire is strung over the machine, it is first placed on a **dolly,** which is a steel pole, a little longer than the width of the wire and suspended at one end. The wire is so looped on this dolly that it can be slid into position parallel to the couch roll,

which is suspended from the back end, and the wire will be in a position similar to that shown in Fig. 56. The wire is then unwound and supported in a similar manner, as shown in Fig. 54, except that it is over the machine. The Fourdrinier part is then rolled back into place and the wire tightened up, after the breast-roll and couch-roll bearings have been returned to their proper positions.

116. Installing Wire on Conventional Machine.—It is necessary to remove all the upper parts of the Fourdrinier when the machine is not equipped with a wire-changing device, as is the case with all the older machines. The slice, deckles, suction boxes, and table rolls are taken out and placed on the tending floor, in such order that each part will be returned to the same place or to its own bearings when the new wire is put in. The save-all boxes and the wire-carrying rolls are next removed, the latter being usually lifted out, or they may be slid out on planks, in the case of large machines and heavy rolls. Then remove the breast roll, by means of the rails and light trucks upon which the roll is lifted with the chain hoist. The upper couch roll is lifted by means of the bell cranks and gear, and the top of the lower-roll bearing is removed.



Roll of New Wire
FIG. 55.

The porter bar is placed in the wire by putting it on the end of the wire pole *A*, Fig. 55, which is in the wire when it is purchased and received. As this pole is pushed out, carefully follow it with the porter bar. When the pole has been replaced with the porter bar, one end of the bar is placed securely over the extension of the lower couch journal, and the other end is lifted by a chain fall (block and tackle) and held in position, so that the end of the couch roll is carried at the right height to allow the new wire to be slipped over it. The lower bearing is removed, and the new wire is then carefully slid over the lower couch roll, great care being taken not to kink it. The roll of new wire is placed on top of the lower couch roll, Fig. 56, pole *A* is replaced in the wire roll, and the wire is unrolled, as indicated by the arrows. Pole *A*, together with the wire on it, is carried toward the flow-

box sufficiently far to permit the breast roll to be placed inside the wire, a few table rolls being replaced to prevent much sagging. The breast roll is slid on a plank (or rails) laid inside the wire, until it can be placed in its bearings, after which, the plank is removed, care being taken not to injure the wire. Only the rolls under the wire (except the upper couch roll) may be left in the machine. Next put the supports and save-alls in their proper places, and then the table rolls, the suction boxes, the carrying rolls, the guide roll, and, lastly, the stretcher roll.

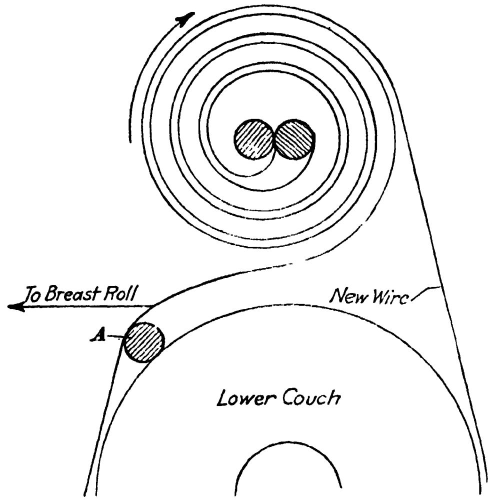


FIG. 56.

The palm or palms on the guide bar must clear the edge of the wire by about $\frac{1}{16}$ inch. See that all pipe connections are tight.

The doctor on the breast roll should have a felt or a rubber edge, to keep the breast-roll surface clean, and to keep any stock from traveling up between the wire and the breast roll, which would cause ridges in the wire. The pressure of the doctor against the breast roll should be as light as possible and still permit it to clean the roll. Any extra pressure will act like a brake, which will increase the work that the wire must do in turning the roll.

When putting on a wire, the entire Fourdrinier part must be cleaned to prevent trouble. It is necessary that the seam on the wire be kept straight, and this cannot be effected unless the guide

roll and stretch roll are square with the machine, and both are level.

117. Testing Squareness of Table Rolls.—The proper way to test the squareness of the table rolls across the machine is to measure with a steel tape, to ascertain whether the distance between the ends of the several rolls is the same on either side of the machine. Care should be taken to select the points at easy places where the measurement begins, and center-punch marks should be made to locate these measuring points. The punch marks should be made directly over the center of the journals of the first press roll or the couch roll.

When satisfied that the measurements are the same on both sides of the machine, measure diagonally to see if the rolls are square with the machine. It is also quite as important to see that the measurement from the center of the front journal of the couch roll to the center of the back journal of the breast roll is the same as from the center of the back journal of the couch roll to the center of the front journal of the breast roll.

118. Leveling and Lining Up the Table Rolls.—When the rolls have been squared, carefully level them across the machine. Line up the rolls by placing a tight wire from the top of the breast roll, and see that light just shows between the wire and the top of each roll; this wire should be drawn tight, from the top of the breast roll to the top of the guide roll. If the breast roll has been raised or lowered, the wire should be straight from the top of the breast roll to the top of the last table roll.

119. Squaring the Other Rolls.—The couch roll and all other rolls must be kept square with the machine; periodical checking of the squareness of the rolls will often prevent undue strains on the wire. The upper couch roll should be so placed that a plumb line dropped through the center of the journal will be nearer to the wet end of the machine than a line similarly dropped through the center of the lower couch roll. Great care must be taken in offsetting the top roll. First see that the distance between these plumb lines is the same at the front, or tending, side of the machine as at the back, or driving, side of the machine; second, that the amount of offset is as much as possible without taking the weight of the upper couch roll off the lower couch roll and placing it on the wire.

120. Starting a New Wire.—When starting a new wire, start slowly, and have all the shower pipes working and the hose going, so that no stock can get between the rolls and the wire. Note whether the wire seam is raised up; if so, pass it over the lower couch roll and flatten it lightly with a wooden mallet. If the seam is raised up, it will cause bubbles across the sheet, because of the air it traps as the raised part passes over the breast roll.

CLEANING THE WIRE

121. Souring the Wire.—If it can be avoided, do not clean the wire with acid; but if this appears to be the only effective method, dilute the acid with water—5 parts of water to 1 part of sulphuric acid. The solution can be applied to the wire through the shower pipes on the inside of the wire. This process is called **souring the wire.** The weak acid solution may be applied on the wire as it comes over the first wire roll. *Always pour the acid into the water.*

A good way to clean a wire with an acid solution (sometimes a caustic solution is used for this purpose) is to make a water-tight box, in which the lowest outside wire roll can run. The roll, turning in the solution, will then sour the wire evenly all over, and the wire will, in its turn, carry around enough solution to sour and clean the whole wire. Be sure not to have the suction boxes in action while the cleaning process is going on; otherwise, the acid (or caustic) will then be lost before it reaches the dandy roll. When the wire and dandy stop frothing freely from the acid bath, they are practically clean; then wash off all the acid with a hose, and clean out the water-tight box. Acid acts chemically on the wire, and it must therefore be well diluted and afterward thoroughly washed off.

122. Pitch in Paper Mills.—Pitch troubles are especially prevalent in paper mills where considerable unbleached sulphite pulp is used, as in making wrappings, glassine, or tissue. Newsprint, groundwood-specialty, and similar mills are also affected by pitch trouble in the paper mill, which is greatly aggravated because the white water sometimes carries large quantities of fines, which are re-circulated to obtain reasonable operating economies.

Pitch commonly appears as 'spots on the wire' or as an accumulation that fills the meshes of the wire and prevents sheet formation at that point. Pitch sometimes collects on the felt as a sticky, dark-brown or blackish material. It also mixes with the fibers and dirt in the system, and shows up as a yellowish, jelly-like substance or a black, sticky lump, which may collect in pipes or on the various parts of the machine.

In spruce, the pitch is in the form of fats or resins. In newly cut spruce, this type of pitch amounts to 2½ or 3 per cent. Such woods as jack pine carry a larger percentage of pitch, sometimes running to 5 per cent, though the average is about 3 per cent. The southern woods, such as loblolly, shortleaf, and longleaf pines, contain up to 20 per cent pitch, depending on the age of the tree, amount of heartwood, and other factors. The sapwood of slash pine contains approximately 3 per cent pitch, or slightly more than spruce. The pitch in all southern pines increases rapidly as the tree grows older and the percentage of heartwood becomes greater. The pitch in newly cut spruce and similar woods has a loose, sticky character. As the wood becomes seasoned, the pitch apparently becomes crystalline because of the oxidation and polymerization of the resin. Wood that has seasoned four to six months will not cause as much pitch trouble in the mill as green wood.

The pitch from the sulphite pulp process presents the worst phase of the problem in the paper mill. Apparently, the pitch is preponderant in the ray cells of the wood. When these cells are ruptured in the cooking and blowing process, the pitch becomes free, and the small pitch particles gradually accumulate into a conglomerate mass, together with some fine white-water particles, which will cause a spot or an accumulation on the wire, rolls, suction boxes, or other parts of the machine. Although there is considerable pitch in groundwood pulp, it does not give so much trouble, since the pitch in the wood is not subjected to chemical treatment, and it does not have the same characteristics as the pitch from the sulphite process.

In general, raw or hard-cooked pulps will give less pitch trouble than a soft or well-cooked pulp; and, if the sulphite is well washed, the pitch content is lower than in a poorly washed pulp. Fresh water and warm water give more complete and satisfactory washing. The use of alum in the sulphite pulp assists in reducing

the pitch difficulty on the paper machines. Clay and bentonite also assist in reducing pitch trouble, since the pitch particles are taken up by the mineral filler. Alkaline materials, as well as glue and starch, have been used to some extent with varying success.

When pitch gets on the Fourdrinier parts of the paper machine, it is usually removed by employing gasoline or kerosene and scrubbing off the spot with a wire brush. Some mills have a strip of felt or wick carrying kerosene in contact with the return wire, which sometimes assists in the removal of pitch particles or spots from the wire. There is no definite method of eliminating pitch difficulties, but the following items may be noted in attempting to remedy them: (*a*) Wood should be seasoned for a period of four to six months; (*b*) where possible, a hard-cooked sulphite pulp should be produced; (*c*) in the manufacture of sulphite pulp, an acid with high free or low combined SO_2 may reduce pitch difficulties; (*d*) the use of clay, bentonite, or similar mineral fillers in the stock reduces pitch on the Fourdrinier part of the machine; (*e*) a well-washed sulphite pulp is usually productive of more satisfactory machine operation; (*f*) alum in the sulphite deckered pulp may reduce pitch trouble; (*g*) kerosene, hypo (hyposulphite of soda), alkali, or similar materials may assist in some cases.

123. Washing the Wire.—Wash the wire plentifully with a hose whenever a chance is offered; this keeps the meshes open, washes off the acid, prolongs the life of the wire, improves the appearance of the paper, and reduces the work on the suction boxes. Many of the troubles on paper machines are caused by the fact that the back side of the machine is not so easily taken care of as the front side; the machine tender should remember this when working on his machine, and should give special attention to the back side.

124. Wire Cleaner.—A recent accessory to the paper machine is the **continuous wire cleaner.** It consists essentially of two narrow brushes, which extend across the paper-machine wire at any convenient point on its return run. The brushes engage the upper and lower surfaces of the wire; they are made to oscillate in opposite directions, so that the wire is subjected to a very thorough and effective scrubbing action, thus preventing the

formation of lumps and spots. The oscillation is effected by a rocker arm, which is connected to a reducing gear, the latter being belted to any convenient wire roll or driven by a small water motor. The power required for driving is negligible.

FOURDRINIER PART OPERATING DETAILS

WIRE, APRON CLOTH, AND SLICES

125. The Wire Guide.—It is essential to maintain the mechanism of the wire guide in good condition, so it will guide the wire in a satisfactory manner without undue wear. If the pan, or palm, exerts too much pressure against the wire, there will be a tendency to wear the edge or cause the wire to crack along the edge. The palm should be renewed whenever it begins to wear badly, and it should be made of the best type of materials. The revolving type of wire-guide palm has proved quite satisfactory, and it appreciably reduces the wear on the guide mechanism, as well as on the edge of the wire itself.

126. Jams or Kinks in the Wire.—A wire is sometimes ridged or kinked when it is being put on, because of uneven tension or buckling of the wire poles. Other similar accidents may slightly damage or crease the very fragile wire, thus preventing the surface from being uniformly smooth. Such a jam or ridge can be partially removed by smoothing out the wire with a curved smooth surface similar to a heavy, glass light bulb. Another method of removing a jam is to place a flat board under the wire and flatten out the injured place with a flexible rubber paddle. Occasionally, the wire is soured with acid and the injured area smoothed down by various methods. Some operators advocate heating the wire and smoothing it out while hot, but this is not usually recommended, since it weakens the wire. Sometimes, the ridge, jam or kink can be removed by gradually tightening down the wire and creating a greater tension. The best cure for these troubles is to prevent them when the wire is being installed; and it should be emphasized that extreme care be taken in the installation of the Fourdrinier wire on the machine.

127. The Apron.—Various types of apron cloth are used on the old-type conventional machine, such as oilcloth of different weights and rubberized materials that are specially made for this

service. In case the machine is idle for any period of time, it is advisable to keep the apron cloth damp, so it will lie flat on the wire.

Sometimes a small piece of apron, a few inches long, is attached to the lower edge of the high-head slice apron board. However, a majority of the high-speed paper machines that employ the newer type of headbox and slice do not use any apron cloth, since the velocity of the stock and speed of travel is sufficiently great to prevent any amount of stock from falling back underneath the apron board.

128. Flow of Stock with Conventional Slice.—On starting, when the paper machine is equipped with the conventional, or straight, slice, it should be so adjusted as to keep the level of the stock higher on the side next the apron than on the machine side. The speed of the stock is kept at approximately the same speed as the wire for high-grade paper. If the stock is flowing onto the wire at a slower speed than the wire is moving, the so-called **fish tails** will appear on the stream of stock up to the point where the speeds are equal. If equality of speed is not attained before the paper is nearly formed, the increasing viscosity of the stock, as it gets dryer, prevents the smoothing out of the surface, and the formation is poor. The paper then lacks uniformity of strength, finish, and thickness, and it may often break before reaching the calenders.

129. Regulating the Slices.—The slices are regulated to suit the kind of stock and the speed of the wire. When the stock is *fine* (or slow) and the water drains slowly through the wire, the amount of water must be decreased, and the slices must be kept down, or there will be little or no pond. As little shake as possible should be allowed. The suction box, or boxes, before the dandy roll should not draw too hard.

When making laid paper, the slices are raised a little higher above the wire than when making wove paper, since more water is required, as the stock is generally more free. When making lightweight papers, the tendency is to let the stock flow slightly slower than the wire is moving. When this occurs, keep the stock back of the slices at a higher level, so as to create more head and get the necessary volume of stock for the same slice opening.

When the stock is flowing too quickly under the slices, which is often the case when making the heavier papers, the head back of the slices should be reduced until the speed of flow is correctly adjusted to the speed of the wire by increasing the slice opening or by shutting off some white water. If there is too much water in the sheet, increase the suction on the first boxes. The thicker the sheet the more shake required.

130. Regulating the High-Head Slice.—The basic principles of stock regulation are essentially the same on both the conventional and the high-head slices. However, the larger volume of stock and the greater volume of flow through the high-head slice intensifies the problem of getting a 'good sheet on the wire.' The pond or head of stock in the flow-box must be sufficient to produce a static head that will force the stock onto the wire at the correct velocity to synchronize with the speed of the wire. On a fast newsprint machine operating at 1250 to 1300 ft. per min., it is necessary to maintain a height of 62 to 64 inches of stock in the headbox.

If the stock is slow, the consistency must be raised and the slice opening increased to get the desired amount of stock on the wire. The flexible-slice lip must be properly adjusted across the wire to maintain a level sheet of stock of uniform thickness. The edges and deckle boards or straps must be correctly adjusted to eliminate side currents at the edge of the sheet. The flat suction-box vacuum must be maintained to remove the proper amount of white water from the sheet and keep it wet just ahead of the dandy. If a shake be used, this should be adjusted to obtain the best results for the particular grade and basis weight of paper being made.

STOCK-REGULATING PROBLEMS ON THE WIRE

131. Consistency of Stock in the Headbox.—The characteristics of the different kinds of pulp used to make the various grades of papers, as well as their blending and preparation, make it necessary to vary the stock consistency in the headbox, in order to obtain satisfactory operation on the Fourdrinier wire. The headbox temperature also has considerable influence on the drainage through the wire, because of change in viscosity of the stock with changes in temperature. A free stock, such as strong

sulphite that has not been treated with Jordans or beaters to any extent, will lose its water quickly when put on the wire. Therefore, for tissue and similar grades, a large amount of water in the sheet is necessary, and the headbox consistency may be as low as 0.10% to 0.15%. The fact that this grade of paper has a low basis weight and is a thin sheet influences the consistency. A grade of paper such as newsprint, which contains 75% to 85% of groundwood pulp, must use a greater headbox consistency, since it is a slower type of stock and the drainage on the wire is slower than for tissue. The consistency for the modern high-speed newsprint machine is about 0.55% to 0.60%. A sheet of groundwood-content heavyweight wrapping paper generally requires a still greater consistency, which may be up to 0.85% to 0.95%. If the chemical pulps, such as bleached sulphite, soda, and old-paper stock, are treated for a considerable time in the beaters and Jordans, the stock is 'slowed up,' and the consistency of the headbox stock is relatively high. The addition of clay and other fillers also influences the consistency, and for book paper and similar grades, the consistency may be about 0.75%.

The following are some average headbox consistencies (per cents); they give an idea of the variation for different grades of paper; they vary from the figures here given in different mills and on different machines:

Grade	Headbox Consistency
Tissue	0.10
Lightweight sulphite wrapping	0.45
Lightweight kraft	0.45
Newsprint	0.55
Groundwood book	0.60
Book	0.75
Sulphite bond	0.75
Heavyweight wrappings	0.85

The above figures are representative only; they may be varied to suit the different operating conditions, basis weights, and other factors.

132. Regulating Stock on the Wire.—When the character of the stock and the headbox consistency have been approximately determined, it is the duty of the operator to adjust the

conditions for the particular machine and grade of paper to secure the best possible sheet on the machine.

The machine tender tries to "put more water into the sheet" on the wire, to improve the formation for any particular grade or basis weight of paper. The addition of 'water' or white water in the sheet means that the stock is a little more diluted and its consistency is lowered. The amount of water that can be used in the sheet is governed by a large number of operating factors, among which are: (1) character of stock; (2) temperature; (3) mesh of wire; (4) number of table rolls; (5) length of wire; (6) number of flat suction boxes and amount of vacuum; (7) shake, and several other less important operating conditions. These must all be recognized by the machine tender in making his adjustments for the correct flow of stock on the wire.

133. Character of Stock.—The amount of treatment of a stock for a specific grade of paper is usually held as uniform as possible. Nevertheless, some variations may occur that will alter the freeness or drainage characteristics when the stock goes onto the wire. If this stock becomes free, it is necessary to carry more water, so the sheet will not prematurely set or form too quickly after it leaves the slice. In case of a slower stock, the opposite action is necessary, and water is taken out of the sheet.

134. Temperature of Stock.—The viscosity of a liquid is greater when it is cold than when warm; hence, a temperature change of the stock will alter the drainage conditions on the wire. This effect may be gradual, but it is of considerable importance in the problem of putting a sheet on the wire. Most mills have a definite summer and winter temperature, and they prepare their stock, use a different mesh, or make other operating changes to compensate for variations in seasonal temperature.

135. Mesh of Wire.—The weave and mesh of the wire have a marked effect on formation on a specific grade of paper. The more modern and high-speed machines are more sensitive to this variation than the older ones. Two makes of wires having the same gauge of shute and warp threads, and woven on a similar reed, may show a slight difference in drainage characteristics. Such a change must be taken into consideration when starting up on the same grade after a shut-down and change of wire.

136. Number of Table Rolls.—The function of the table rolls is to assist in the removal of water as well as to support the wire. Theoretically, a large number of table rolls will remove more water from the sheet in its travel down the machine. The size, or diameter, of the table rolls and the distance between them is also a factor in water removal. The larger ones are considered more effective.

It is absolutely essential that all table rolls be in balance, and do not wabble or whip, because one bad roll may destroy the formation of the sheet. These rolls should be of such material as brass, chromium-nickel steel, or rubber-covered steel, which does not corrode and become rough, since this may also interfere with sheet formation.

137. Length of Wire.—The length of the wire and the distance between the apron and the dandy have a direct bearing on the amount of water that can be put into the sheet in making a specific grade of paper. If the wire is too short, it limits the sheet-forming area.

138. Number of Flat Suction Boxes and Amount of Vacuum.—These two factors are closely related, since their combination removes the water from the sheet before it reaches the suction couch roll. With more suction capacity, it may be possible to carry more water in the sheet and obtain better formation.

139. Shake.—The frequency and amplitude of shake has a definite effect on sheet formation. Most modern shakes are so made that the number of movements per minute, and also the throw or length of the shake, can be varied and adjusted. A change in shake conditions will often alter the sheet on some grades of paper, and will be a factor in the amount of water that can be put in and taken out of the sheet.

140. Running Stock on Conventional Machine.—When making envelope, cartridge, or any paper for which stock may have been kept too long, and is therefore *soft*, it is necessary to use plenty of water, raise the slices, and give a vigorous shake. However, too much shake may make the edges of the paper thin, on account of the back washing from the deckle straps.

Because of poor design of the flow-box and apron board, it is sometimes necessary to check the flow of stock at certain points across the slices, with pieces of paper, etc., so as to get an even

stream across the machine. Weights are often placed on the apron, in the stream of stock, to correct such unevenness of flow. It is better to correct these conditions by raising the slices somewhat, using more water, and increasing the flow from the box.

When stock is soft and fine, it will look greasy, and it may stick to the first-press roll. Use as little water as possible and as much suction as possible, and keep the couch roll down hard.

With soft, fine stock, weight the couchers well, and set the guard board close to the jacket, but keep the jacket wet enough to prevent rubbing off dust from jacket or board. Use but little weight on the first press, and keep the wet felt fairly tight.

141. Keeping Water in the Stock.—In making a high grade of paper on a long wire, the paper may have a dull, crushed look, more especially if it be a wove paper, on account of too much water leaving the stock at the table rolls before proper formation is accomplished. This may be remedied by preparing slower stock.

When a minimum quantity of water passes through the wire, the paper will reach the couch roll with a larger proportion of the sizing and loading originally placed in the beater than when an excess of water is used. Too rapid drainage of water can be prevented on some machines by lowering several table rolls out of contact with the wire.

Whether the stock has the right amount of water may be judged by the position and regularity of the line over the first or second section box, which shows when the web becomes noticeably dryer. The proper position of this line depends on the grade of paper and the kind of watermark.

The fibers must remain in suspension long enough to get the degree of felting required by the grade of paper being made. On high-speed machines (800 to 1200 feet per minute), a wire 80 to 100 feet long is used. Velocity of stock flow is obtained by increasing the head in the headbox or by elevating the breast roll; but these adjustments must conform to the speed of the wire and to the kind of stock being used. Where a well-closed sheet is wanted, and to secure the full effect of the shake, the breast roll may be lowered 2 or 3 inches below the couch.

On news, kraft, wrapping, and cheap book, start with water, then very dilute stock, say 300 parts of water to 1 of stock, and

let the excess return to the regulating box, through the save-alls and white-water pump. If this procedure is not followed, the screens may fill up and the wire may be flooded with excess stock.

On slow stock—rag paper, fine writings, ledgers, bonds, etc.—it is best to start with about 50 parts of water to 1 of stock, and then gradually increase the water supply, if found necessary.

142. Regulating the Suction.—If the stroke of the shake be too long, the stock will wash back from the deckle straps, thinning the edges and causing a mark about 2 or 3 inches from the edge of either side. The deckle straps should have clean, square edges, and rest flat on the wire.

There should be a sufficient number of suction boxes on the machine to keep too much water from going over to the couch roll. Use no higher vacuum than is necessary for safe running; this may vary from 2 to 10 inches or more. But if there are not enough boxes, a greater vacuum must be used in order to do the work. When 10 inches or more of vacuum is used, the life of the wire will be shortened. Too much suction on the boxes will sometimes prove an excessive load, and will cause the lower couch roll to slip on the wire. If the box covers are of wood, see that they are planed smooth, so the wire will not be forced to follow the ridges it makes in the covers. Also see that the box covers are thick enough to keep them from vibrating when a strong suction is carried.

The pipe to the vacuum gauge should be located as near the outlet of each box as possible, since gauges on headers some distance from the boxes are liable to be read incorrectly. It is advisable that pressure and vacuum gauges reading a few inches of mercury or pounds per square inch be checked by means of mercury U gauges. Many times, indicating gauges are found to be incorrect.

143. Foam.—When making soft-sized paper, *foam* is liable to cause trouble. The slices should be lowered and more water used, so that the foam is kept back of the slices. The bubbles that gather on the edge of a laid dandy roll can be kept away by rubbing a little oil on the dandy, just off from the edge of the paper, or by oiling the wiper cloth just over the edge. Bubbles at the edge indicate bubbles clear across; and a steam pipe and wiper should be used across the entire roll. Some foam-killing

mixtures are effective. A good formula usually contains a sulphonated oil. The student should refer to the applications of pH control, as explained in *Sizing of Paper*, Vol. IV.

Kerosene is also a good foam killer, and it can be advantageously used by suspending a 5-gallon can of it over the suction of the white-water pump. Sometimes kerosene or other oils are fed to the machine at the mixing system or at the headbox. In some cases, the foam-killing mixture is dumped into the beaters before emptying them. A good spray, preferably rotating or oscillating over the pond or flow-box, is usually very helpful.

To keep the dandy roll free from foam when making laid papers at high speed, place a perforated pipe in front of it, so that a little steam may be blown across the surface.

144. Enlarging the Watermark.—Sometimes it is necessary to have the watermark in the paper slightly larger than the size of the marks, or the distance between them in the paper must be slightly greater than the spaces on the dandy roll. One method suggested is to let the wiper cloth bear sufficiently hard on the dandy to slow it up just enough to gain a little. A safer plan is to increase the effective diameter, and thus reduce its speed slightly. The best way is to prepare the stock as free as possible; then tighten all draws (the pull between sections), to get a little more stretch, and tighten up the dryer felts so as to hold the paper close to the dryers and prevent shrinkage. In this manner, a dandy mark may be stretched a full $\frac{1}{8}$ inch.

Lack of uniformity in the dandy marks across the machine, if the dandy is straight, is probably due to improper crowning of the press rolls; this makes the paper either wetter at the ends than in the middle or vice versa. When the paper is not uniformly pressed, the wetter parts are stretched more on the dryers than the dryer parts. When setting a dandy, be sure that the deckles and markings are right; that is, set it so that the edges of the paper come the proper distance from the marks.

THE COUCH-ROLL JACKET

145. The Couch Roll.—The upper couch roll should not be couched too much; it should be so adjusted that the weight of the upper couch roll is carried entirely by the lower couch roll and that no part of its weight is carried by the wire.

The holes of a perforated roll keep water and wool balls from collecting under the jacket and causing the jacket to creep and move around the roll. These holes may convey quite a little water into the inside of the upper couch roll, but it will be squeezed out by the nip between the rolls or by the squeeze action of the guard board.

146. Putting On a New Jacket.—When a new jacket is put on the couch roll, it should be of the right size for the machine and of the right character for the kind of paper to be made. The felt maker should be given full information as to the requirements to be met, and he should also be fully informed regarding any defects in the jacket after being put into use.

The old jacket is cut lengthwise, and the wire is driven forward until the jacket is clear. The new jacket is opened on the clean machine floor and carefully measured. Should it appear small, it can be stretched a little on a stretcher, shown in Fig. 57. The

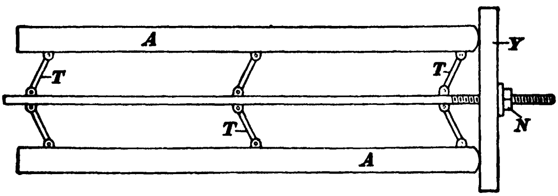


FIG. 57.

hard maple beams *A*, rounded on the outside, over which the jacket is stretched, are supported clear of the floor, and they are pushed apart by the toggle joints *T*, by turning the nut *N* against the yoke *Y*. This can be done while the upper couch roll is being prepared. There are several designs of jacket stretchers.

When the ends of the jacket are held tight by clamping rings—screwed or bolted against the end of the roll, or if the jacket is sewed fast, each end is punched—about 3 inches from the edge, with a row of $\frac{1}{4}$-inch holes, about 6 inches apart, and threaded with stout twine. Slip the new jacket over the lifting or porter bar used for putting on the wire, making sure that the nap shall be smoothed down as the jacket runs under the guard board.

147. Couch-Roll Jackets.—The couch roll on a Fourdrinier serves two main purposes: the first is to transfer the paper from the Fourdrinier wire to the felt; the second is to squeeze out as

much water as possible in the process. In order to withstand this great pressure, the jacket must be very strong and firm; if it does not have the proper strength, this pressure causes it to become loose and to get baggy on the roll.

The guard board has more to do with the length of service received from a couch-roll jacket than any other one factor, since undue pressure on the guard board causes the jacket to wear very rapidly, and it has a tendency to make the jacket become loose and get lumpy on the roll. Guard boards should have a beveled edge and should be kept in good condition. If the jacket be shrunk on evenly and firmly at the start, and if proper care be exercised regarding the pressure applied to the guard board, good results can usually be obtained.

148. Shrinking the Jacket.—After the jacket is put on the roll, it must be shrunk on, to grip the roll tightly. This is accomplished by pouring several pails of extremely hot water across the roll very quickly while turning. When the jacket is firmly set, check further shrinking by starting the cold-water shower. Lower the guard board carefully, and set its edge so that the jacket will be uniformly dry for its full length, using as little pressure as possible.

149. Starting a New Jacket.—When starting a new jacket on fine stock that is liable to stick to the nap, use as little weight on the roll as possible, and put the guard board down fairly tight. Before starting, pour a few handfuls of white clay or filler on the jacket, so that the nap may be flattened and the jacket made harder by closing the pores with the clay or filler. When the shower on the working edge of the guard board is turned on, the pipe should be so turned that the jets will play on the front of the guard board, the water running down the front onto the jacket. If the jets play on the new jacket, the nap will rise, and the liability of *picking up* the paper will be much greater. But if the paper should pick up, a little turpentine or rosin size poured on the jacket will stop this.

150. Jacket Troubles.—A new jacket often causes trouble when colored papers are being made, since the picking up of fibers causes marks on the surface of the paper. If the guard board allows water to pass, the jacket will pick up stock as it runs onto the wire. Brushes that have been weighted with lead and placed

on the jacket in front of the guard board will keep the jacket clean. A brush of fine brass wire, or a piece of woolen-mill card, may be used on jackets. Turpentine is good for cleaning the edges of the couch roll where the picking up is worst.

If the jacket seam is not straight, it may be straightened by increasing the couch-roll weights on the side where the seam is traveling ahead; this will produce a drag on this side of the wire, which will straighten the seam. Adding weight in this manner may, however, cause lumps of wool to gather inside the jacket, and it may also make the paper thinner on one side.

THE SUCTION COUCH ROLL AND SUCTION BOXES

151. Amount of Suction.—A majority of new and renovated paper machines are equipped with suction couch rolls. The operator must be careful not to get too much suction in the suction boxes, since this may cause the wire to be slack after leaving the suction roll, and make it wrinkle. The best way to determine how much suction to use is to watch the wire after it passes the suction roll, and, if it gets slack, reduce the suction on the boxes until the slack wire below draws tight enough to run safely without wrinkling. On free stock, such as news, cheap tablet, catalog, wrapping, etc., it is practically impossible to get too much suction, because air penetrates the sheet easily.

152. Braking Effects.—The action of the suction boxes in drawing the wire down to the surface of the box results in a brake effect on the wire. The greater the suction the greater this brake effect, which must be overcome by an added pull by the surface of the lower couch or suction roll, to drag the wire away from the suction boxes. The couch roll will sometimes slip under the wire, if the load it pulls is too great; this may break the paper on the machine, because of a momentary variation in the speed of the wire. The doctors on the breast roll and other rolls can also act as brakes. Anything that the machine tender can do to reduce the amount of pull on the wire by the couch roll, without spoiling the papermaking function, will increase the life of the wire.

153. Making the Wire Run True.—If the wire guide will not keep the wire true, and the wire tends to travel to one side, the trouble may be in the suction boxes. The wire will sometimes wear grooves in the suction-box covers, causing it to 'hang'

on the flat suction boxes. When this occurs, the guides cannot help matters, and the only remedy is to cut off the vacuum and move the box so the wire will enter the grooves. This action will sometimes occur when the machine is equipped with oscillating or moving suction boxes, usually being caused by an excess vacuum. If the boxes are removed and planed, it may help to correct the trouble.

MISCELLANEOUS

154. Oscillating Suction Boxes.—The movement, or oscillation, of the flat suction boxes assists in guiding the wire and in making it run true; it is standard and essential equipment on the high-speed and modern machine.

There are several ways of oscillating the flat suction boxes. The most common and satisfactory method is a reciprocating motion across the machine. This movement is produced by connecting rods attached to a series of cams on a shaft that is driven by a motor, and parallel to the frame of the machine. These cams are so arranged that no two boxes are moving in exactly the same direction at the same time. The *throw*, or lateral movement of each suction box, is usually about $\frac{1}{2}$ to $\frac{3}{4}$ inch, and the number of oscillations varies from 12 to 45 per minute, depending on the speed of the machine and the other operating conditions.

Another type of oscillator produces both a cross and a diagonal movement; and still another variation gives the box or group of boxes a reciprocating motion, the operating mechanism of the latter being so arranged that the end of the boxes on the front side of the machine will move a short distance down the wire and, at the same time, the end of the back side will move up the wire an equal distance. When the maximum movement is reached, the action is reversed.

The speed of oscillation on the last two types is much slower than that of the one first mentioned, and it is not so effective. The mechanism for driving these oscillators is similar in principle, although the general effect is somewhat different.

155. The Showers.—The patented shower pipes use less water per minute and, at the same time, throw a stronger stream than the old type. This patented shower pipe is more economical of

water, and it also does its work better. A rough figure that is approximately correct for the old-fashioned shower pipes, operating under 35 pounds water pressure, is $1\frac{1}{2}$ gallons of water per minute per inch of width of machine; the modern, patented shower pipes will save about one-third of this water.

If the shower pipes are not doing good cleaning work, increase the water pressure and keep the holes clear. Use filtered water. The effect of an increase of water pressure on the shower pipes is to increase the force of the showers; it also increases the consumption of water. For instance, a forty-eight-hole, old-fashioned shower pipe, $1\frac{1}{4}$ inches in diameter, with $\frac{1}{16}$-inch holes, spaced $\frac{1}{2}$ inch between centers, gives the following water consumption:

At 10 pounds pressure, 13.3 gallons per minute.
At 20 pounds pressure, 15.5 gallons per minute.
At 30 pounds pressure, 18.2 gallons per minute.
At 40 pounds pressure, 21.6 gallons per minute.
At 50 pounds pressure, 25.0 gallons per minute.

In selecting the spray pipe, the nozzles that give the finest spray, and which throw the spray so it falls over a large area of foam, should be selected. These pipes are generally located over the flow-box, over the apron, and just back of the slices; their sole duty is to reduce the accumulation of foam.

156. Self-Cleaning Shower Pipe.—A patented shower is made of standard brass pipe, in three sizes—2, 3, and 4 inches in diameter—according to the length required. To this pipe are fastened brackets for the support of a $\frac{1}{2}$-inch brass rod, which can be removed endwise on the pipe by means of a handle. The holes are oval in shape, approximately $\frac{1}{8}$ inch in diameter at the small end and $\frac{3}{8}$ inch at the large end. Deflectors of a special design are fixed on the rod at proper intervals, so that, as the rod is moved, they will cover and uncover the large end of the holes. A lip on the deflector acts as a guard against splashing when the large hole is exposed and the pipe is being cleaned.

When the shower pipe is in operation, the deflectors cover the $\frac{3}{8}$-inch holes and leave exposed the $\frac{1}{8}$-inch holes. The water discharges against the deflectors and spreads out into fan-shaped streams, which emerge as a solid sheet of water about 3 inches from the pipe.

The pipe is cleaned by shifting a lever handle, which moves the deflectors and uncovers the $\frac{3}{8}$-inch holes. The torrent of water discharging through these relatively large holes effectively removes any gathering of fibers or other impurities that would tend to clog the $\frac{1}{8}$-inch holes. The work of cleaning is a matter of seconds; consequently, there is no interruption to the work that the shower performs.

157. Cost of Fresh Water.—The consumption of water in the manufacture of pulp and paper is of major importance to any mill. The amount of fresh water per ton of paper will vary according to the type of mill and with the grade of paper being made. There is also a wide range of fresh-water consumption in mills making similar grades of paper. Some newsprint mills use as high as 50,000 gallons per ton of paper made, though the average is approximately 25,000 gallons per ton. Some groundwood specialty mills that use considerable lapped groundwood or sulphite, can reduce their fresh water consumption to 5000 to 10,000 gallons per ton of finished product.

The amount of white water utilized by its re-use throughout the plant, is the most important feature in the consumption of fresh water. In all modern mills, the white-water system has been so arranged as to use white water instead of fresh water wherever possible, as in the screens, showers, beaters, and similar places. This conserves the fresh water, and it also saves the loss in fiber and other papermaking materials; because it is obvious that for every gallon of fresh water coming into the mill, there must otherwise be an approximate equivalent amount of white water leaving the plant.

A 300-ton paper mill using 50,000 gallons of water per ton of product requires a fresh-water supply of 15,000,000 gallons per day, an amount sufficient to supply a city of 20,000 population. This might be considered as the maximum requirements of any paper mill, most plants using only a small proportion of this volume of fresh water.

If the paper mill is situated on a river that provides reasonably clear, clean water, the cost of water is often a minor item. But if it is necessary to pump water from a distant lake or other fresh-water supply, the cost per ton of product is increased. In many cases, it is also necessary to use a filtration plant in order to get

pure, clean water. This subject is further discussed in the Section on *Water and Steam*, Vol. IV.

Under average conditions, where a considerable part of the water supply must be pumped and treated to some extent, the cost of power, labor, and treating materials amount to 2 or 3 cents per 1000 gallons. If the cost of a filtration plant be included, the cost of fresh water would be materially increased; consequently, it is of importance to every paper mill to take all possible steps to conserve fresh water in the various papermaking processes.

158. Distribution of Water on Paper Machines.—The utilization of white water was shown diagrammatically in Fig. 10. Grades of paper using stock at consistencies of 0.5% to 0.6% in the headbox require large volumes of water in constant circulation through the regulating box, mixing box, wire, and trays. The use of water in circulation on a newsprint machine, as illustrated by the diagram, Fig. 10, is approximately as follows:

FOR MACHINE MAKING 120 TONS OF PAPER PER DAY

	Gal./day	Gal./min	Per cent
Incoming water and stock (assuming stock in headbox 0.6% b.d.)	7,200,000	5000	100.00
Removed by wire (assuming that stock leaves last press 12% a.d. fiber)	6,937,920	4818	96.36
Removed by press part (assuming that stock leaves last press 33% a.d. fiber)	200,160	139	2.80
Removed by dryers (assuming that dried sheet contains 92% a.d. fiber)[1]	59,040	41	0.80
Water left in sheet (assuming that sheet contains 8% water)[1]	2,880	2	0.04

[1] These assumptions closely approximate the operating conditions for some grades of paper, but cannot be applied to all. The above figures apply to the volume of water under these specific conditions.

159. Water in Circulation on a Machine.—The white water in constant circulation through the wire into trays and back through the mixing box and headbox, represents the largest percentage of water used on the paper machine. Assuming that fresh water replaces white water going to the sewer on the basis of 15,000 gallons per ton of paper, the total of 6,938,000 gallons per day in circulation on the wet end of the Fourdrinier is divided approximately as follows:

	Gal./min.	Per cent
Tray and suction water in constant circulation (total wire water minus fresh water)	4236	87.9
Fresh water on screens	107	2.2
Fresh water on headbox showers	100	2.1
Fresh water on wire showers	300	6.2
Fresh water showers on jacket and dandy	75	1.6
	4818	100.0

The preceding figures illustrate the approximate distribution of white and fresh water for a specific condition; they are subject to many variations, depending on the grade of paper being made and the operating conditions of the paper machine.

Many mills have substituted white water for fresh water on the screens, a number of them successfully use white water on the wire showers. Fresh water is necessary to clean felts, but this goes into the pit under the felts, and it carries little fiber to the sewer. The water for felt showers is used only during wash-ups, and it represents but a small percentage of the total requirements.

160. Temperature of Water on Paper Machines.—The seasonal variation in stock and water on the paper machines is greatly influenced by the volume of fresh water, at river temperatures, that is used. The temperatures of stock in the headbox of a representative large newsprint mill are 50° to 55°F. in the winter and 70° to 75°F. during summer months. The fresh water represents 10% to 12% of all water used on the machines. The temperatures of the incoming fresh, or river, water averages 35° to 40°F. during the winter and spring months, and 60° to 65°F. in the summer and fall.

The tray and suction water in constant circulation tends to standardize the temperature of the stock entering the mixing box for any particular season. The fresh water used on the screens, headbox, wires, and felts is usually taken from the river, and it lowers the temperature of the stock entering the mixing box in proportion to the volume and temperature of the fresh water used.

161. Compressed Air.—The reciprocating double-acting air compressor shown in Fig. 58 consists of a frame *A* on which is mounted air cylinder *B*. A piston *C* is given a reciprocating

motion in the cylinder by piston rod *D*, crosshead *E*, connecting rod *F*, and crank shaft *G*. The shaft *G* carries belt wheel *H*, through which the compressor is driven from some source of power. At the ends of the cylinder are the suction valves J_1 and J_2 and the discharge valves K_1 and K_2.

The operation is, briefly, as follows: When the piston moves, say from left to right, a partial vacuum is created in the cylinder, the pressure of the atmosphere forces inlet valve J_1 to open, and air enters the cylinder at atmospheric pressure. As soon as the piston reaches the end of its stroke and starts to move to the left, it begins to compress the air in the cylinder, the inlet valve

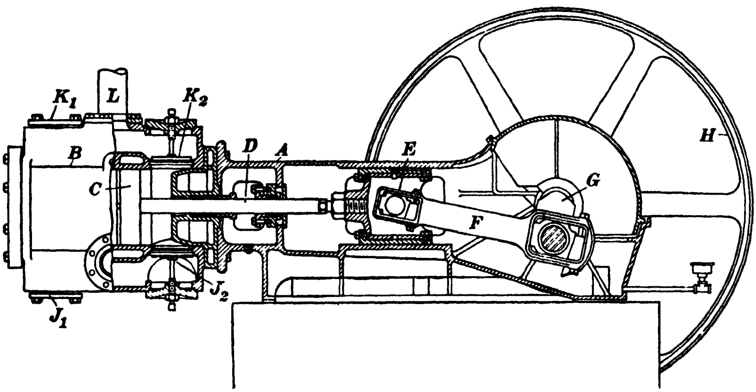


FIG. 58.

J_1 closing. When the pressure of the air in the cylinder equals that in the discharge line *L*, the outlet valve K_1 opens, and the air in the cylinder is forced into the discharge line. While the air is being discharged from the left end of the cylinder, discharge valve K_2 is closed, and air is being drawn into the other end of the cylinder through inlet valve J_2. This latter air is compressed on the return stroke and is discharged through outlet valve K_2.

In order to provide a certain amount of storage for the compressed air, a receiver is connected to the discharge line from the compressor on one side and to the mill air-pipe line on the other side. The receiver provides a reserve supply, so that the pressure will not fall too far below normal if there is a momentary demand for air greater than the ordinary capacity of the compressor. The receiver is provided with pressure gauge, safety valve, and a

drainage connection to remove the water that condenses from the compressed air.

162. Operating Variables on Wire Part of Paper Machine.—There are many variables in the papermaking process that affect (to some degree) the operating conditions of the machine and the properties of the resulting sheet of paper. One of the major problems in paper-machine operation is to control all these variables within a reasonably narrow range of fluctuations. Many can be, and are, regularly checked and numerically recorded in the well-controlled paper mill; others are detected by the experienced paper-machine operator. But even the most complete data and the best papermaking knowledge does not completely correct any particular difficulty, because many of these variables are dependent on each other, and a combination of operating conditions may occur that will apparently conflict with any previous experience or calculations. The following is a fairly complete list of headbox and wire variables:

1. Freeness or quality of the stock to the machine.
2. Consistency of the stock in the headbox.
3. Temperature of the stock in the headbox.
4. Height of the stock in the headbox.
5. The pH value of the stock.
6. Type and design of the slice.
7. Number of slices.
8. Position of end of apron board or apron cloth.
9. Relation between slice and breast roll on high-speed machine.
10. Amount of slice opening or setting.
11. Relation between velocity of stock going to wire and speed of wire.
12. Pitch of wire.
13. Type and mesh of wire.
14. Number of table rolls.
15. Distance between table rolls.
16. Diameter of table rolls compared with speed of machine.
17. Material used for table-roll covering.
18. Type and number of baffles between table rolls.
19. Type and setting of deckle.
20. Speed or frequency of shake.
21. Amplitude of shake.

22. Type of shake mechanism.
23. Location of dandy roll.
24. Diameter and surface speed of dandy.
25. Weight applied to sheet by dandy roll.
26. Wire-mesh cover of dandy roll.
27. Construction of dandy-roll frame and bearings.
28. Number of suction boxes.
29. Material of suction-box covers.
30. Size, shape, and location of openings in suction-box covers.
31. Distance between suction boxes.
32. Location of suction boxes.
33. Amount of vacuum on each suction box.
34. Diameter of suction couch roll.
35. Construction of and number of holes in suction couch rolls.
36. Vacuum on suction couch roll.
37. Setting of vacuum box of suction couch roll.
38. Location of rider roll.
39. Location of the draw roll.
40. Diameter of top couch roll (when used).
41. Material and cover of top couch roll.
42. Position of top couch roll relative to bottom roll.
43. Pressure applied by top couch roll.
44. Adjustment of pressure by guard board.

Some of these variables relate to the construction of parts of the machine and of materials used. Many other variables may influence operation, because of poor mechanical condition of the equipment, defective bearings, etc.; but these purely mechanical defects should not be confused with the actual variables listed above.

PAPERMAKING MACHINES

(PART 1)

EXAMINATION QUESTIONS

1. Name the principal parts of a Fourdrinier paper machine and explain briefly the function of each.

2. Explain fully what happens to the stock in the stock chest until it reaches the paper machine.

3. What is the main function of the water used to carry the paper fiber onto the wire?

4. What happens to the paper if the excess water is not removed before the paper reaches the couch rolls?

5. Describe the course of the water used at the wet end of a paper machine.

6. How can sand and other impurities be removed from paper stock?

7. Describe a regulating box and explain its purpose.

8. (*a*) If you were building a mill would you install a save-all? Why? (*b*) What kind would you select? Why?

9. Explain the operation and advantages of (*a*) a flat screen; (*b*) a rotary screen.

10. Where are the following parts, and what are they for: (*a*) flow-box? (*b*) shake? (*c*) dandy roll? (*d*) guard board? (*e*) apron? (*f*) deckle straps? (*g*) guide roll? (*h*) suction box? (*i*) stretch roll? (*j*) slice?

11. (*a*) What is the function of the couch rolls? (*b*) Compare the effects produced by the couch press rolls and the suction couch roll.

12. Explain the action of the table rolls in removing water from the paper.

13. (*a*) What effects are produced on the stock by raising or lowering the breast roll? (*b*) by using more or fewer table rolls?

14. What is the difference between (*a*) a right-hand and a left-hand machine? (*b*) between the front side and the back side?

15. Why is it necessary to have rolls square with the machine? How are they tested for squareness?

16. How is the paper taken from the wire to the first-press felt?

17. (*a*) What is white water? (*b*) Why is it so important to reclaim it?

18. Explain fully the effect of the mesh of the wire on the formation of the paper.

19. Describe how an old wire is removed and a new one put on.

20. (*a*) About how much fresh water per ton of paper is used in your mill? (*b*) If you had full authority, what would you do to reduce this?

SECTION 1

PAPERMAKING MACHINES

(PART 2)

THE PRESS PART

DEWATERING THE PAPER

163. Function of the Press Part.—When the wet sheet of paper is transferred from the wire to the first-press felt, its composition is approximately 15 per cent fiber and 85 per cent water. As previously explained in Art. **45,** the transfer of the wet sheet is made by cutting a narrow lead strip, about 3 to 6 inches wide, by means of a squirt and lifting over to the first felt by an air jet inside the suction couch roll, or by hand when the machines are equipped with the top and bottom couch rolls. Papers of very light weights, such as tissues, are transferred from the wire to the first press by a pickup felt, which contacts the top of the sheet at the couch roll and lifts it from the wire because of the texture of the felt and the characteristics of the lightweight sheet.

The principal function of the press part is to remove more water from the sheet, although it also acts as a medium to make the sheet more compact and smoother. When the reverse third press is used, it is of more importance as a smoothing medium on the wire side of the sheet, particularly on book, bond, and other similar grades of paper.

164. Per Cent of Stock and Water.—The table on page 116 shows the approximate per cents of stock and water at various points on the paper machine.

Water does not leave book paper as readily as it leaves news; hence, book paper leaves the Fourdrinier and enters the dryer part carrying a greater per cent of water than does news. The

per cent of stock on book paper will be approximately the same as on papers where bleached sulphite stock is used. Water leaves paper made of unbleached sulphite more readily than from any other that has had the same preparatory treatment; therefore, more water can be pressed out by the couch action and also by the presses, the felts do not fill so easily, and a greater pressure can be applied on rolls. This grade of sulphite paper leaves the presses dryer than either news or book papers.

	News (1200 ft. per min.)		Book (400 ft. per min.)		All sulphite (400 ft. per min.)	
	Solids	Water	Solids	Water	Solids	Water
Mixture going on wire..	0.5–0.6	99.5–99.4	1	99	1	99
Leaving couch rolls.....	15	85	17	83	25	75
Leaving last press......	26–30	74–70	29	71	40	60
Leaving dryers.........	91–94	9–6	91–94	9–6	93	7

165. Cost of Water Removal by Presses.—The mechanical removal of the water in the sheet by the presses is much more economical than evaporating it by the dryers. It costs approximately twelve times as much to remove the water by the heat of the dryers as by the presses. This ratio of costs will vary to some extent, depending on the value of the steam consumed and the final moisture per cent of the sheet as it comes from the dryers.

The importance of efficiently operating the press part is of major significance on such machines as news and kraft, where volume production is essential. This is illustrated by the curve, Fig. 59, which indicates the variation in steam consumption at different per cents of water in the sheet entering the dryer part. When the cost of steam per 1000 pounds is available, it is possible to calculate the theoretical difference in cost to dry paper under the varying conditions of operation.

166. Water-Removal Factors on Suction Press.—The modern paper machine that is equipped with suction presses must be handled somewhat differently than the conventional-type press part. Some of the important factors of the water-removal

problem on a high-speed paper machine are: (*a*) type and weave of felt; (*b*) type of suction-press roll; (*c*) pressure per inch of roll; (*d*) crown of top and bottom press rolls; (*e*) character of stock and speed of operation.

For machines manufacturing high-grade and specialty papers, quality is usually considered of major importance, and it is

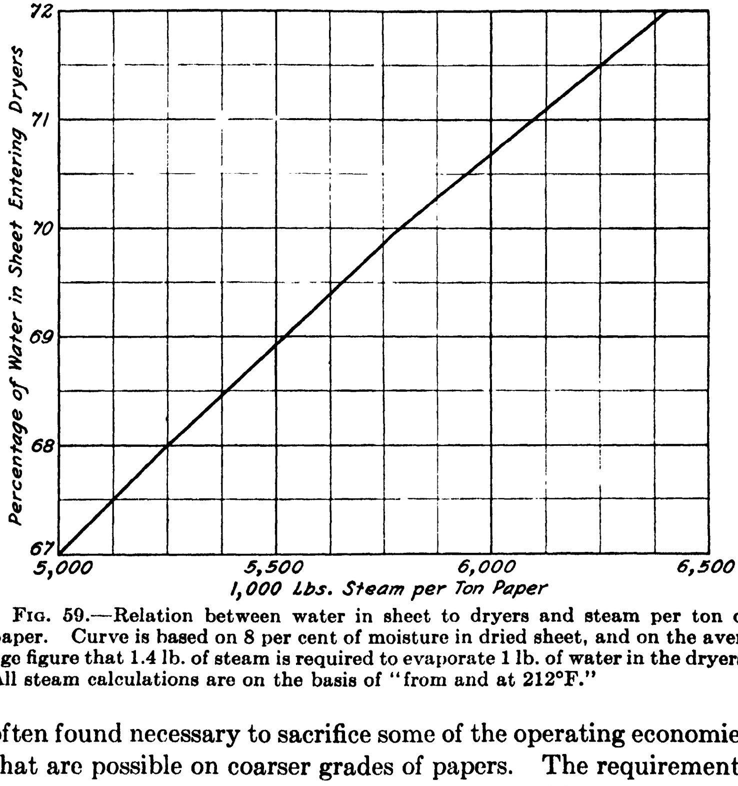


FIG. 59.—Relation between water in sheet to dryers and steam per ton of paper. Curve is based on 8 per cent of moisture in dried sheet, and on the average figure that 1.4 lb. of steam is required to evaporate 1 lb. of water in the dryers. All steam calculations are on the basis of "from and at 212°F."

often found necessary to sacrifice some of the operating economies that are possible on coarser grades of papers. The requirements of each grade must be considered when making a study of this problem.

DESCRIPTION OF PRESS PART

167. Purpose and Limitations.—The press part consists of two or three sets of press rolls, through which the paper passes. Four presses have been tried, but were not practical because the fourth press does not remove sufficient water to pay for its operation.

Many machines have only two presses; and, if these are equipped with suction-press rolls, satisfactory results are obtained. With three presses, the first press usually squeezes out the most water, the second less, and the third only a little.

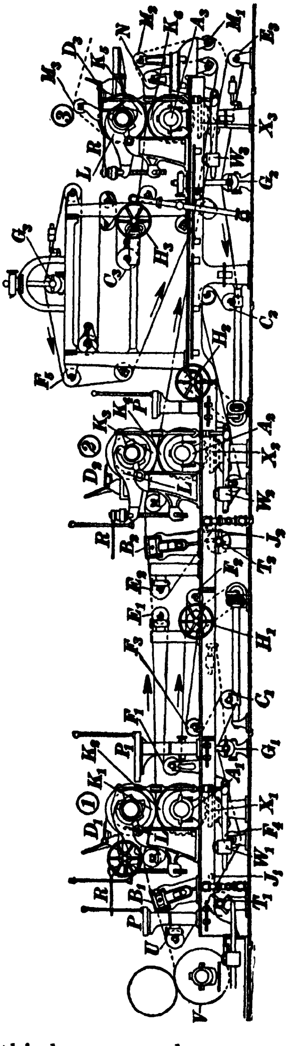


Fig. 60.

It is extremely difficult to dry paper or pulp by mechanical pressure beyond the point where it has less than 60% of contained water; it is very unusual to find a press part on a paper machine delivering paper at the dryer end containing less than 70% water, the remaining 30% being paper stock. A news sheet leaves the last press of the machine with a 'bone dry' fiber content of about 30%.

168. Course of the Paper.—The paper in the press part is conveyed on felts through the nip of the presses. The lower rolls, unless suction rolls, of the press are rubber covered, and the upper rolls are made of hardwood, granite, composition, cast iron, or have a bronze outside casing. Fig. 60 shows a press part for a high-speed machine, which consists of three presses, the paper being reversed on the third press. Where only two presses are used, the paper is reversed at the second press.

Many high-speed news, kraft, and other machines have a 'straight-through' third press. This type of third press reduces many operating difficulties, and has been selected for most of the modern news machines.

The machine tender passes the paper from the couch roll *V* onto the felt of the first press at roll *U*; the felt carries the paper

over the suction box B_1; from thence it travels over a felt roll that is so placed that the felt and paper run down toward the nip of the first pair of press rolls K_1 and K_2. This arrangement keeps the water that is squeezed out by the press rolls from running onto the incoming felt and paper, since it is thereby forced to run down the near side of the lower press roll. This position of the felt roll also keeps air from being pocketed between the paper and the felt. The platforms P and P_1 allow the machine tenders to cross the machine.

As the paper passes through the first press, it leaves the felt and clings to the first upper press roll until it reaches the doctor D_1, by which it is scraped off and where it accumulates as wet broke in an inclined V-shaped trough, which is formed by the doctor blade and the back retainer wall that is built onto the doctor. This wet broke, or waste paper, is sent back to the broke beater or beater room.

The bottom roll of the first press is covered with rubber; the upper press roll is of wood (maple), cast iron, cast iron with a brass sleeve, or stone (polished granite), the brass sleeve and stone rolls giving the best surfaces for enabling the papermaker to skin the paper off the upper press roll before transferring it to the wet felt. The felt carries it forward, and it is passed by the machine tender from roll E_1 to roll E_2, on its way to the second press.

When the machine is provided with a cut squirt, this is set to give a strip from 3 to 6 inches wide, which is peeled off the upper press roll by picking the edge with thumb or finger nails, or blowing it off by compressed air; sometimes it is laid over a small roll, and placed on the felt, against which it is held until the drag of the felt is sufficient to pull the paper from the roll. It is fed into the nip of the second press and the cut squirt pushed across the wire. Sometimes this strip, widened to 8 to 10 inches, is carried well over the dryers before the full tail is cut.

If a cut squirt is not used, the machine tender gets as much as he can pull away from the front edge, then the back tender peels the remainder away gradually until the paper is all on the felt.

After leaving roll E_1, the felt passes around felt rolls F_1, F_2, F_3 to stretch roll C_1; then over guide roll G_1 to felt roll F_4, under shower pipe J_1, past whipper T_1, to roll U. The course of the other felts may be traced similarly. In Fig. 60, the felts are

indicated by full lines, and the paper is indicated by dotted lines.

The doctor D_1, etc., is liable to scrape grooves into the upper roll; for this reason, it is supplied in many cases with a vibrating mechanism, which will be described later.

169. Course of Press Felts.—Before leaving the first press and following the course of the paper, observe how the first-press felt gets back to the first receiving roll. The first-press felt is a long one, and the extra length is sometimes carried to a roll in the basement. This felt must be of rather open weave, to allow the large quantity of water that is squeezed out at the first press to pass through it. The second-press felt is generally finer than the first-press felt; that is, it is softer and has more nap, so as to produce a smoother finish on the paper as it passes through the nip of the press roll. According to the kind of paper being made and the treatment that the felt receives, the first-press felt becomes hard in the course of a few weeks, or even sooner. The pores are filled with filler that will not wash out, and it is usually necessary to remove the felt before it is worn out. It is the general practice on news machines so to design the first-press part that the felts used on it are of the same length as those on the second press, in order that they may be interchangeable if operating conditions permit the use of a felt on either press. In the design shown in Fig. 60, the felt on the second press is long, because the paper is reversed at the third press, and this necessitates that the second-press felt travel the full distance under the third press. The felt stretcher C_1 is actuated by the hand wheel H_1, by means of a sprocket chain and two sprocket wheels, in a manner to be described later.

170. Size of Felt Rolls.—The usual sizes of felt rolls and their journals for different widths of machines are given in the following table, all dimensions being in inches:

Width of machine	100	125	150	175	200	225	250
Sizes of rolls	$6\frac{1}{2}$–7	$7\frac{1}{2}$–8	$8\frac{1}{2}$–9	$9\frac{1}{2}$–10	$10\frac{1}{2}$–11	$11\frac{1}{2}$–12	$12\frac{1}{2}$–13
Sizes of journals	$1\frac{7}{16}$	$1\frac{11}{16}$	$1\frac{15}{16}$	$2\frac{3}{16}$	$2\frac{7}{16}$	$2\frac{11}{16}$	$2\frac{15}{16}$

171. Course of Paper (Continued).—The machine tender, or the back tender, passes the paper from the first-press felt, as the felt turns down on felt roll E_1, Fig. 60, to the second-press felt, as it turns up on felt roll E_2. The paper is carried by the second-

press felt over the felt suction box B_2 (not always used), and over the felt roll, which is raised above the nip of the second press, in exactly the same manner as it passes to the first press. The doctor, the press housing and arm, the weights and levers, the stretcher roll C_2, and the guide roll G_2, are the same in all respects as those of the first press; the course of the felt, however, is different, as will be seen from the illustration.

The paper is to be reversed at the third press, in order to bring the wire side against the upper third-press roll, so the impressions of the wire may be removed by the smooth surface of the upper third-press roll. To carry the paper far enough forward in the machine to allow of its return in the reverse direction through the third press, it is necessary to make the second-press felt carry the paper to roll E_3. The machine tender takes the paper from the second-press felt at roll E_3, passes it over paper rolls M_1 and M_2, and places it on the third-press felt at roll N. If the paper were to pass direct to roll N, it would break. The paper rolls M_1 and M_2 give the paper plenty of slack and allow enough give and take in the pull of the third-press felt to permit the paper to be laid on this felt without undue strain, with its consequent breaks, since the narrow tail of wet paper is very weak.

At the third press, the paper enters the nip of the press rolls from a felt roll whose top is higher than the nip. The paper is carried around by the face of the upper press roll in the third press in exactly the same manner as in the other two presses, because it sticks to the surface of the roll until it is scraped off by the doctor D_3, where it forms wet broke. The tail is skinned off the press roll by the machine tender, who passes it over the paper roll M_3, which is so supported by brackets that it is higher than the top of the upper press roll. From this point, the paper is passed over to the dryers. Skinning the narrow strip of paper from the roll requires skill and practice. Unless the machine is provided with compressed-air nozzles, or rope carrier, the edge is broken by the finger nail, quickly torn across, then pulled away, and the strip carried forward, over the paper-carrying rolls, and passed to the smoothing press or the first dryer.

172. Rope Carrier.—The rope carrier is sometimes used on a reverse third press to convey the narrow strip (tail) through the

reversing (third or fourth) press and on to the dryers. Two ropes are provided, running close together on sheaves or grooves at the end of the press rolls, and kept taut by idler and take-up sheaves. The lead strip is blown from the top press roll by a blast of compressed air; the machine tender slips the paper between the ropes, and the strip is carried around the rolls and transferred to a similar set of ropes on the dryers.

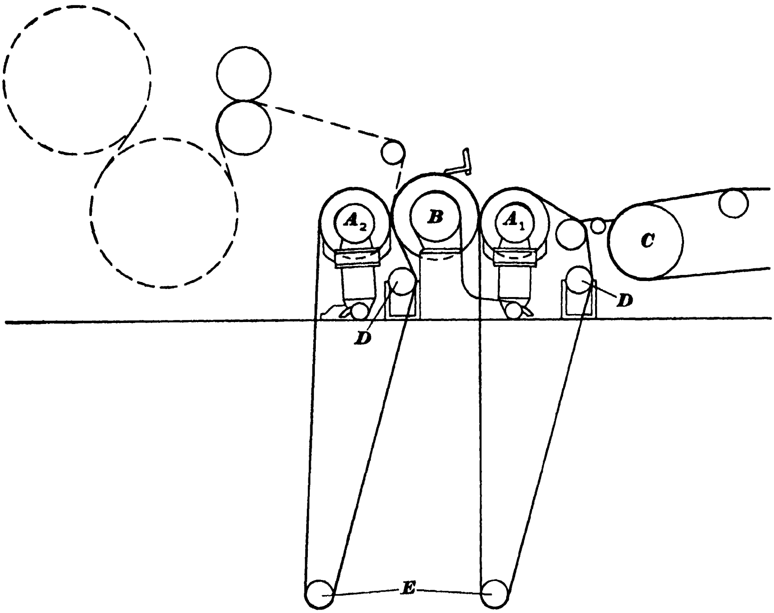


FIG. 61.—*A*, suction-press rolls; *B*, stone or metal press roll; *C*, suction couch roll; *D*, automatic felt guide; *E*, felt stretch roll.

The third-press felts pass around the stretch rolls C_3, the guide rolls G_3, and the felt rolls F_5, etc. On some machines, there is a very light belt from the felt rolls to the paper rolls; and the pulleys may be heavy enough to act as flywheels. It is decidedly advantageous to use ball bearings. When not so provided, it is usually necessary to start the rolls turning by hand.

Fig. 60 shows the characteristic features of a press part of a paper machine, including the reversal of the paper, which is generally done at the last press, regardless of whether there are two presses or more than two.

There is a slight increase in surface speed at each successive press, from presses to dryers, which is called the **draw,** a term also applied to the unsupported paper passing from one part to another.

173. Dual Press Section.—A recent development in the application of the suction-press roll is to use a pair of suction rolls *A*, *A*, Fig. 61, with a plain press roll *B* between them. The sheet from the wire part goes over the first suction couch roll, under the press roll, and over the second couch roll. The pressure is maintained by a heavy spring adjustment, which presses the rolls together, and this double suction roll press will usually do the work of two regular presses. It requires a space equal to about one regular press, and the felts, which run into the basement, are much shorter than those of the conventional press. The space saved is available for the installation of additional dryers.

DETAILS OF PRESS PART

PRESS HOUSINGS

174. Types of Press Housings.—Fig. 62 shows typical sketches of four different designs of press housings; designs (*a*) and (*b*) are for use on light, narrow machines, while designs (*c*) and (*d*) are for use on heavier, wider machines. These designs will now be considered in the order named.

The housing (*a*) has a swinging arm *B*, pivoted at *P* on frame *F*, which carries the journals *J* of the upper press roll *K*. The lower press roll K_1 is supported by journals in separate bearings on the press frame, as indicated at A_1, A_2, A_3, Fig. 60. Arm *B* is raised or lowered by turning hand wheel *W*, which turns screw *S* through the pivoted nut *N*. The reader will note that this is a lever of the third class.

In the case of the housing shown at (*b*), the operator raises or lowers the arm *L* carrying journal *J* of the upper press roll *K* by turning the hand wheel here indicated by the circle *W*. The shaft of this hand wheel carries a worm *G*, which meshes with the worm gear *N*; the latter acts as a stationary nut, and raises or lowers the lifting link *S*, thereby moving the swinging arm *L* about the pin *P*. *F* is a felt roll, and *H* is a hook for attaching the

levers to put extra pressure on the upper roll. (See W_1, W_2, and W_3, Fig. 60.)

In the case of the housing shown at (*c*), the swinging arm *L* is raised or lowered by means of the hand wheel *W*; this housing is the reverse of that shown in (*b*). The bevel gear *G* on the hand-wheel shaft meshes with a larger bevel gear *N*, which acts as a nut and screws the lifting screw *S* up or down, thus raising or lowering the upper press-roll arms.

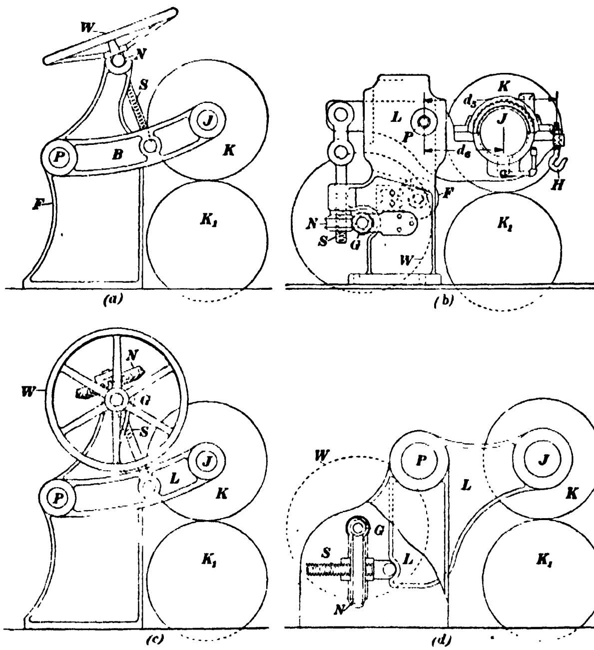


FIG. 62.

In the housing shown at (*d*), the swinging arm *L* (a bell crank) carries the upper press roll *K*, and is raised or lowered by means of a hand wheel, which is here indicated by the dotted circle *W*. A worm wheel *G* is keyed to the hand-wheel shaft and meshes with a worm gear *N*. The latter turns as a stationary nut for screw *S*, which causes screw *S* to push against the lower corner of the bell-crank lever *L*.

The upper roll is not always directly over the bottom roll; the line of contact may be slightly toward the in-running side: this is called the **offset.**

175. Roller-Bearing Housings.—The roller bearing has been adopted as standard equipment on the Fourdrinier part of most modern paper machines; it reduces friction and the drag or slippage on the top of the sheet. The bearing housing shown in Fig. 63 is somewhat larger than the conventional type, Fig. 62, but the principles of lifting and lowering the top press roll are similar. The journal *C* (*J*, Fig. 62), of the top press roll *K* is carried by the rollers *B*, Fig. 63, in the housings *A*, which is supported by the frame *F*. The roll is lowered or raised by means of the hand wheel *W*, Fig. 62, which turns the screw *S* and lifts the roll, which is supported by the arm *A*, Fig. 63. Various

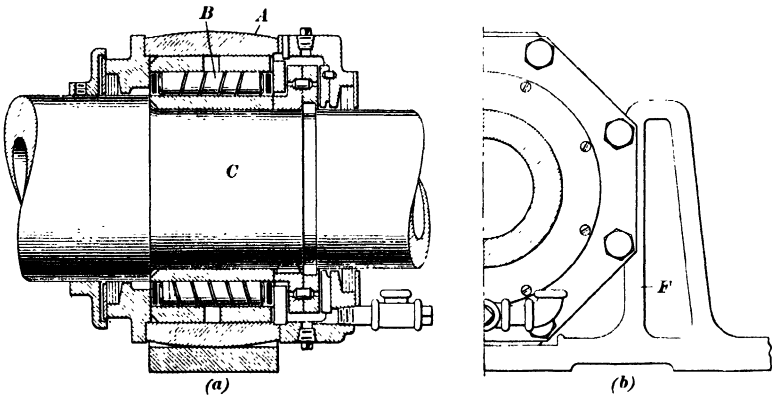


Fig. 63.

modifications of the lifting device are used, but the principles are essentially the same.

PRESS-ROLL WEIGHTS AND LEVERS

176. A Typical Arrangement.—Fig. 64 shows a typical arrangement of weights and levers for controlling the pressure of an upper couch roll, or an upper press roll, on the paper and on the lower roll. The hanger is made in four parts, the top part hooking into the swinging arm at *H*, Fig. 62 (*b*), that carries the top roll; in Fig. 64, this part is simply an eye bolt *B*. The second part is the turn buckle *T*, which is used to adjust the length of the hanger. The third part *H* completes the turn buckle. The fourth part *E* is a long eye bolt that carries lever *L*, which presses with its short end under the flange of the press frame, as shown

in view (*b*); it is hung, and pulls down on the center of the hanger *E* at *P*, holding hanger *F* on its long end. Hanger *F* is a tee-(T) headed bolt, the tee head resting on the long end of lever *L*. The nut on the bottom end of *F* holds in place a wedge-shaped washer casting *C*, on which rests the lever *G*, the hanger *F* passing through the lever. The short end of lever *G* turns on pin *M* as a fulcrum, and, on the long end, the necessary weights are placed, as shown at *W*.

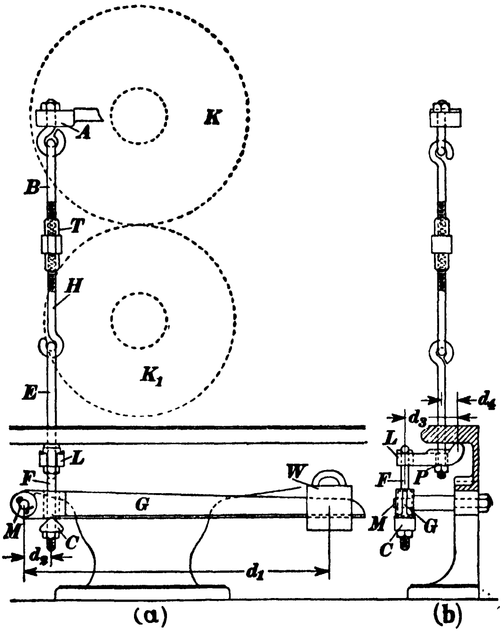


FIG. 64.

177. Pressure Produced by the Weight.—If the weight *W*, Fig. 64, be so placed that the distance d_1 from the center of gravity of the weight to the center of the pin *M* is 8 times the distance d_2 between the center of the wedge-shaped casting *C* and the center of the pin *M*, then the resultant pull downward on hanger *F* is 8 times the weight *W*. If *W* weighs 50 pounds, the downward pull (p_1) on *F* is $8 \times 50 = 400$ pounds; this is exerted on the end of lever *L*, the length of whose power arm is indicated by d_3, and the length of whose weight arm is indicated by d_4. Suppose these lengths are carefully measured, and it is

found that $d_3 = 3 \times d_4$; then the resultant pull (p_2) on E is 3 times the pull on F, or $400 \times 3 = 1200$ pounds, which is exerted downward on the swinging arm that holds the upper roll. The arrangement is evidently a compound lever, in which the power arms are represented by d_1 and d_3, and the weight arms by d_2 and d_4. Since $d_1 \div d_2 = 8$, and $d_3 \div d_4 = 3$, the velocity ratio of the combination (its mechanical advantage) is $8 \times 3 = 24$. Therefore, the pull on E is $50 \times 24 = 1200$ pounds, the same result as before.

In the housing shown in Fig. 62, (*b*), the ratio of the lengths of power arm d_5 and the pressure arm d_6 is, say, $d_5:d_6 = 13:9$. Therefore, the total theoretical pressure exerted at the line of contact of rolls K and K_1 by the weight W is $50 \times 8 \times 3 \times \frac{13}{9} = 1733\frac{1}{3}$ pounds. The velocity ratio of the entire combination is $8 \times 3 \times \frac{13}{9} = 34\frac{2}{3}$. Since there is a similar combination on either end of this roll, a pressure of at least $1700 \times 2 = 3400$ pounds will be obtained on the nip between the rolls by hanging a weight of 50 pounds on the levers G, Fig. 64, in the position shown; and to this must be added the weight of the top roll. It is, however, the weight per inch width of press roll that counts in pressing the paper.

178. Press-Roll Details.—When a machine is exceptionally wide, the top press roll is exceptionally heavy; it is not good practice to subject the rubber covering of the press roll to a pressure of more than 50 pounds per lineal inch of face, more especially, if the rubber covering be soft. This pressure is often largely exceeded to the detriment of the rubber covering. The machine tender should add only weight enough to cause the top and bottom rolls to meet at every point across the line of contact.

Rubber covers on lower press rolls were used at first, instead of wood and brass coverings, for two reasons: one reason was to save the felt; the other reason was to obtain a compressible roll, to compensate for insufficient crowning. The weights (W, Fig. 64) are used for obtaining the necessary compression of the roll surface, to close all gaps between the press rolls. On narrow machines, a softer rubber covering can be used than on wide machines; and the use of levers and weights on the press arms is more practical for the correction of the small errors in crowning that may occur on machines up to, say, 120-inch face of rolls.

On wide machines, a closer approximation to the correct crown, when the bottom roll is first crowned, permits the use of a stiffer rubber covering and a less extensive use of levers and weights. Wide machines have very heavy upper press rolls; indeed, it is hard to design them so they will not exceed 50 pounds weight per inch of face.

Many machine tenders, when coming on their shift, alter the position of the weights on either the couch roll or the press roll, because every man has his own ideas regarding this; but the pressure should always be as light as possible on a wide machine. If a press roll be not ground accurately, and is larger in diameter at one end than at the other, the paper will be dryer at the larger end, if the same weights are used.

Sometimes the steam in the dryers is not properly controlled, and one side, sometimes the side on the front of the machine, may be colder than the other side; so the machine tender tries to correct the lack of uniformity of drying by changing the weights on the upper press rolls; but this is poor practice.

Press rolls should be carefully calipered with micrometer calipers, the diameters being taken for every 6 inches of their length. A record should be kept of these measurements; and if the record be plotted, it will show the shape of the roll and be a useful guide to re-grinding. The plot is made by making an outline of the roll and indicating the diameters at the proper distances across it. The plot shows the diameter as measured at the distance indicated from the end of the roll.

The conventional paper machine uses top press rolls that are driven by the friction on the top of the sheet. The adoption of roller bearings for such rolls has greatly reduced the possibility of slippage between the top press roll and the sheet. Some paper machines are equipped with driven top press roll, on the theory that the bottom and top rolls should be synchronized in speed to reduce slippage between the roll and the sheet. These drives are both electrical and mechanical, and can usually be installed on existing presses without too much trouble. In addition, the use of the drive on top press rolls has some other advantages. The slippage can be eliminated, which will usually result on somewhat better finish on the top side of the sheet. In some cases there is an increased felt life and some general improvement in the operation of the press, due to this type of drive, which is better

adapted to some types of paper than to others. When consideration is being given to the installation of a top press drive, all factors must be taken into account, in order to determine whether or not it is an economical and satisfactory unit for the particular machine where the installation is to be made.

DOCTORS

179. Stationary Doctor.—Many slow-running machines, as well as high-speed news and kraft machines, use a stationary doctor on the top press rolls. If a granite or composition roll, with characteristics similar to the stone roll, is used, a thin, flexible blade is employed for the doctor, which is accurately balanced, so that the pressure on the roll is just enough to cause the flexible blade to ride evenly on the face of the roll and remove all crumbs and particles of fiber. The blade is softer than the roll, and it gradually wears down evenly without cutting the roll. The blades are easily changed when worn down, and they function in a satisfactory manner if properly fitted and maintained.

180. The Oscillating Doctor.—Some of the doctors on the older machines bear heavily on the roll, and the blade is of hardwood, metal, or hard composition. If this doctor were to remain fixed in position while scraping, it might soon reproduce its own inequalities on the shell of the press roll, its edge scratching and scarring the surface. To prevent this, doctors are provided with an auxiliary mechanism that causes them to oscillate to and fro, and this motion results in a smoothing action between the edge of a doctor and the surface of the roll.

181. Description of Oscillating Mechanism.—The mechanism for moving the doctor is shown in Fig. 65. A worm casting W is fastened to the press-roll journal by set screws; it meshes with the worm wheel W_1, which is keyed to shaft S. As the top press roll turns, worm W turns with it, and this causes worm wheel W_1 and shaft S to turn also, but very slowly compared with the speed of the roll. One end of lever L is fastened to the top of shaft S by a tap bolt T_1, the center line of which is eccentric to the center line of the shaft S; hence, the center line of T_1 revolves around the axis of the shaft when the shaft S turns, and this causes the end of lever L to turn around the same axis. This movement compels the other end of the lever, which is fastened

by tap bolt T_2 to doctor D, to move to and fro a short distance in a direction that is across the machine, and thus gives the doctor an oscillating motion. The position of the doctor blade with reference to the top of the roll is adjusted by means of screw V; there are two such screws, one at either end of the doctor. The doctor blade may be made of steel, brass, rubber, or vulcanite; the last two substances have less wearing action on the roll,

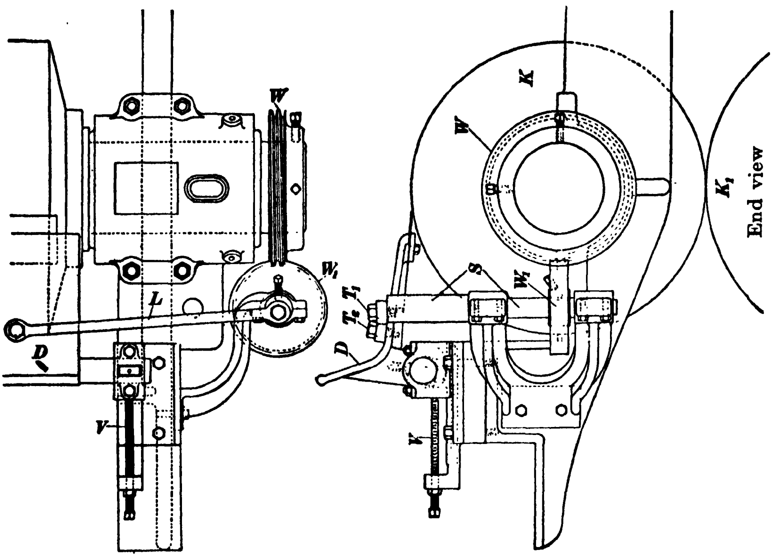


Fig. 65.

and they do not rust or corrode. A patented doctor blade, made in narrow sections and practically flexible, may be had.

SUCTION-PRESS ROLLS

182. Lining Up the Suction Rolls.—Suction-press rolls are used on the first and second presses of most modern paper machines. The mechanical operation of the suction-press roll is much the same as that of the suction couch roll, and the same degree of care must be exercised to get the suction roll lined up with the rest of the machine.

The position of the suction box inside the suction roll requires very careful adjustment. On account of varying conditions, it

may be necessary to try the suction box in several positions before the correct one is definitely determined. Some experimenting may also be required in connection with the kind of felts used, it having been found that what works well in one mill is not always best suited to conditions in another mill. The felts used on a suction press roll are not usually turned over, and, such felts need be napped on one side only. A suction press-roll felt should last much longer than the old-style press-roll felts, since the action of the suction will keep the felts clean.

183. Construction and Operation.—The top roll is usually granite or wood, or it may be rubber covered, depending on the character of the paper being made. The face of the suction press roll is straight, and the top roll, the function of which is to smooth the surface of the paper, must be crowned. If wet streaks appear in the sheet as it leaves the suction press, it is possible that the top press roll is either unevenly weighted or is incorrectly crowned. The top roll should not be weighted any more than is absolutely necessary, since the suction of the bottom roll does most of the dewatering. This latter feature accounts for the ability to make a bulkier sheet over suction rolls. As it leaves the suction-press roll, the sheet should be carried up over a draw roll of small diameter.

As fast as any water is pressed out by the top roll, it is immediately carried away by the bottom suction roll. This eliminates the usual pond of water that collects at the nip of plain press rolls, which is caused by the up-coming surface of the plain bottom roll constantly carrying the pressed-out water back into the nip of the rolls. This action further eliminates blowing, crushing, felt marking, and such kindred troubles as are caused by the objectionable pond of water that is always seen at the nip of plain press rolls.

Large volumes of air are constantly being drawn through the felt and into the suction roll; this action tends to keep the felt open and clean, so that less frequent washing is required. On machines making krafts and manilas, for instance, no felt washing is done, except at the time of the regular weekly shut-down.

The suction press largely prevents first-press breaks, irrespective of the condition of the stock and of the speed of the machine. The atmospheric pressure holds the sheet down on the felt, while

it passes over the suction area, with a force sufficient to overcome its natural tendency to stick and follow up on the top roll.

184. Rubber-Covered Suction-Press Rolls.—The rubber-covered suction second-press rolls are adaptable to many grades of paper. The use of a rubber-covered suction roll for the first press is not fully successful on some grades of papers, since there is a tendency for the holes in the bottom roll to become obstructed with fine fibers of stock, which are pulled through the felt by the suction action of the vacuum.

The shell of the suction roll is covered with about 1 inch of rubber, of a density of about 40. The holes in the suction rolls are made clear and smooth, to prevent plugging. The bottom suction roll, with a rubber covering of this type, provides a cushioning effect, so that the pressure of the stone roll on the felt does not cause the felt to wear as rapidly as when stone top and bronze suction rolls are used. It is possible to weight the rubber suction press heavier, to remove more water, and at the same time get a longer life on the felts on most grades of paper.

FELT SUCTION BOXES

185. Description of Felt Suction Box.—Felt suction boxes are similar in design to the wire suction boxes, except that no arrangement is made for reducing the suction area when a box without cover is used; that is, the rubber piston and the adjustments for it are omitted. The felt suction box shown in Fig. 66 is made from a pipe *P*, on top of which is a trough *A* for the purpose of keeping the felt *F* from actual contact with the pipe and closing the holes *H*, which are 2 inches in diameter. As the felt passes over the trough, the suction tends to draw the felt down into the trough, up to the holes *H*. Since the felt is being stretched tight as it moves, the force of the suction simply draws the felt down, as indicated by the dotted line in the end view, just enough to make the contact between the felt and the edges of the trough sufficiently air-tight and water-tight to allow the strip between the edges of the trough to have a part of its contained water sucked out and drawn into the pipe *P*. The suction box is drained at *S*. A perforated wood top similar to the type used on the wire is preferred by many, who claim this type is less wearing on the felt.

186. Operation.—Felt suction boxes are generally placed below the felts, just before they enter the nip of the first and the second presses. If the felts are kept as dry as possible, the presses are helped in their work of pressing the water out of the paper into the felt that carries the paper between the presses. The edges and tops of felt suction boxes must be kept as smooth as possible, to guard against damaging the felt as it passes over the box and is dragged into it by the suction.

Felt suction boxes are built in many ways, and a perforated cover, similar to that on a wire suction box, is used. There should be a smooth surface, with no sharp edges that will wear the nap off the felt. This type of cover is made of wood, with diagonal slots, which overlap enough to provide a drying action over the whole width of the felt.

The suction box acts also like a brake on the felt, and a heavy suction will probably shorten the life of the felt.

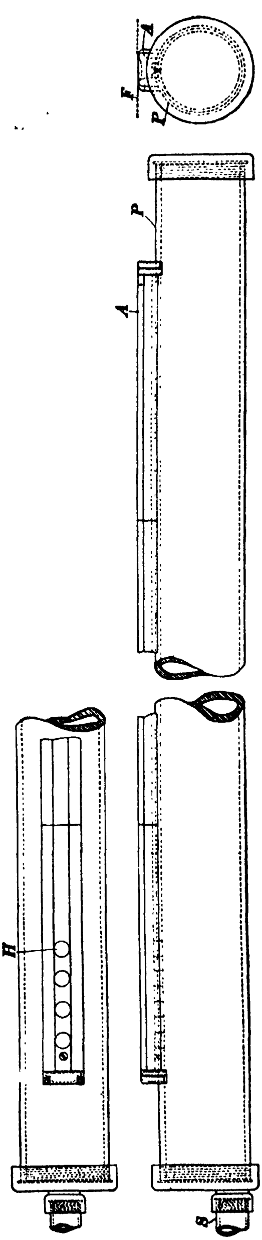
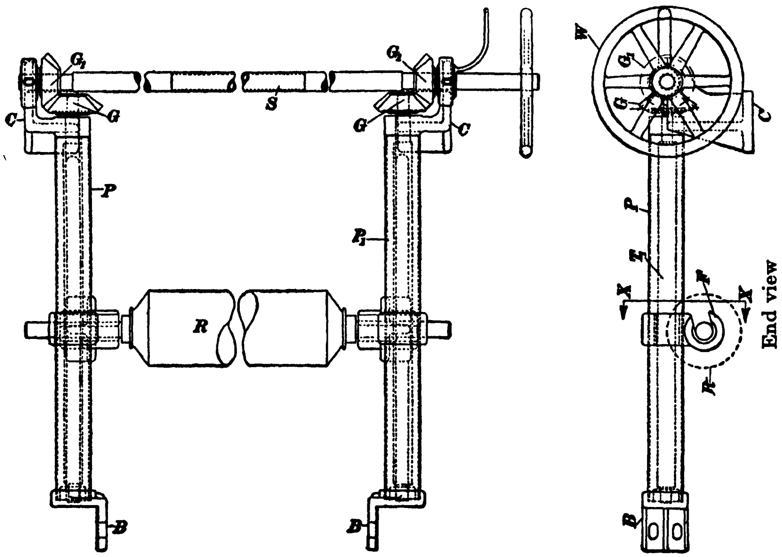


Fig. 66.

PRESS-FELT STRETCHERS

187. A Typical Design.—In Fig. 67 is shown a typical design of a hand-operated stretcher for a press felt. The press-felt roll *R*, which carries the half lap of felt, is supported by journals that turn in the brackets *F*; and a screw thread *T*, Fig. 68, in each portion of the brackets fits inside the brass pipes *P* and P_1. In both pipes, there is a slot throughout nearly its whole length, to allow the brackets to slide along the outside of the pipes and also

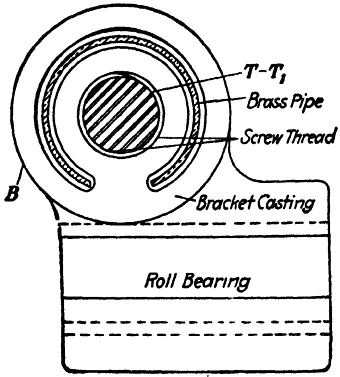
to project inside, so as to engage the threaded shaft T_1 that runs inside the pipe. Fig. 68, which is an enlarged sectional view,



Plan

FIG. 67.

shows this detail more clearly. The screw T_1 can turn, but cannot move otherwise. The screws have bevel (miter) gears G at one end, the gears G_1 meshing with them being on shaft S. By turning hand wheel W, shaft S and the miter gears revolve; this causes the screws in the pipes on either side of the machine to turn equally until the brackets carrying the felt roll are in the correct position to keep the felt in the state of tension required. Fig. 67 shows the stretcher furnished with a bracket B on one end of each pipe, to bolt to the side of a housing or upright casting, and a bracket C on the other end, to bolt to the press frame.



Section on X-X Fig 67. (Enlarged)

FIG. 68.

188. Velocity Ratio of Stretcher.—This stretcher gives the machine tender a velocity ratio of several hundred to one, according to the pitch of the screw and the other dimensions. Fortunately, the efficiency of such a piece of machinery is not over 25%; otherwise the felts would be overstretched more than they are now on many a machine.

It is customary to have a cam arrangement that will throw out the gears on the front side, so the back end of the stretch roll can be operated forward or backward of the position of the front end, in order to make up for inequalities in the length of the felt.

FELT WHIPPERS AND SHOWERS

189. Felt Whippers.—The felt whipper, see Fig. 69, is designed with 2, 3, or 4 blades *A*, which are bolted to spiders *B*. The blades are made almost always of wood, and the outer extremities are rounded to an arc of a circle, as shown. Brass pipes may be used instead of blades. The spiders *B* are mounted on a shaft *S*, which carries the driving pulley *P*. The whippers are placed on the outside of the felt; they revolve at about 125 r.p.m., and in a direction such that the edge of the blades will not knock the nap off the felt. The rapid motion of the whipper causes the felt to vibrate forcibly against its blades, which beat out the dirt from the felt. A strong shower is directed against the inside of the felt, to wash out the loosened dirt. Felt whippers are almost always omitted on fast machines.

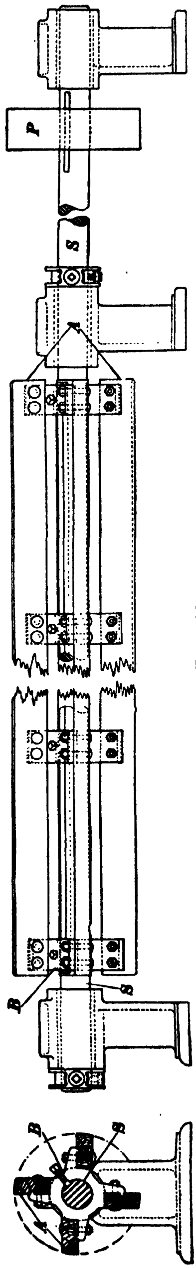


FIG. 69.

190. Washers.—There are several patented attachments for washing felts without stopping the machine; for the most part,

these consist of a shower to distribute warm water, soap, or a chemical solution, and a suction box to draw out the dirty water and loosened dirt. On some machines, a pair of squeeze rolls are used to remove the water used for washing the felt.

Some experiments have been made in connection with the use of a steam jet instead of a shower; but the higher temperature is apt to shorten the life of the felt.

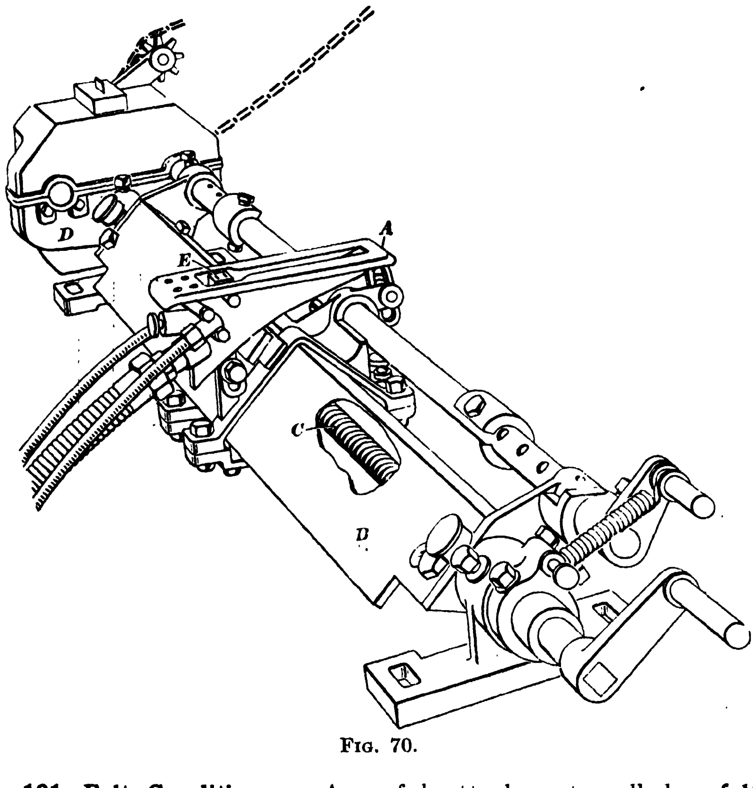


FIG. 70.

191. Felt Conditioner.—A useful attachment, called a **felt conditioner**, shown in Fig. 70, consists of one or more conditioning boxes *A* (depending on operating conditions and width of felt), mounted on slide *B*. A screw *C*, which is operated by an automatic reversing mechanism *D* driven by a belt from one of the roll shafts, causes the conditioning boxes to travel back and forth from one side of the felt to the other. The conditioning box is provided with a means for passing hot water through the felt

and a suction means for withdrawing this water, together with the dirt that has been loosened by it. The box is connected with a small hose, to provide water, and a large one which is connected to the vacuum pump.

The speed of the box is such that the felt makes one complete turn during the time the box is traveling the width of the nozzle, and thus every thread is acted upon. Hot water is ejected from the nozzle E, passes through the threads of the felt, and is immediately sucked back, thus cleaning and opening, (conditioning) the felt. The bottom suction roll keeps the felt comparatively clean. This equipment is not usually needed on the modern

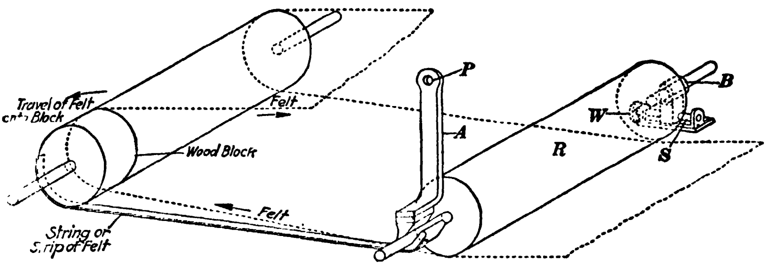


Fig. 71.

high-speed machine, but it is used to a considerable extent on paper machines of the older type.

GUIDE ROLLS AND PAPER ROLLS

192. Autoswing Guide Rolls.—Fig. 71 shows the guide roll G_1, Fig. 60, in greater detail. The bearing of one journal of the guide roll R is hung at P from a pivot on the tending side of the machine. The bearing of the other journal is carried in a bracket B, which is moved by an adjustable hand screw S. When the hand wheel W on the end of this screw is turned, the bracket carrying the guide roll is caused to move by means of the screw thread that is tapped in the bracket, and in which the hand screw turns. The position of the roll is so adjusted by this means that the felt has a slight tendency to come to the front (tending) side of the machine.

The front journal, whose bearing is in the swinging arm A, is connected by a string or strip of felt to a cylindrical wooden block which fits loosely on the end of an adjacent felt roll (as F_5, F_4, Fig.

60). When the felt travels to the front side of the machine, it climbs onto this wooden block and turns it; this causes the string or cable to wind up on the block and pulls the guide roll toward the block, thus correcting the travel of the felt. The principle is the same as that explained in connection with the wire guide roll. Fig. 71 shows the arrangement in perspective. It is customary so to hang the front end of the guide roll that the felt will be guided forward again when the felt has left the block after the travel has been corrected. When the felt has left the block, a counterweight draws the string back to its former position.

193. Paper Rolls.—Since the paper is weak when wet, it is important that the rolls over which the paper travels shall turn very easily; for this purpose, the bearings must be well lubricated. Ball or roller bearings are a distinct advantage, and are used as standard equipment on most modern machines.

MANAGEMENT AND CARE OF PRESS PART

CARE AND TREATMENT OF FELTS

194. Taking Off the Old Felt.—The old felt is cut across the machine, and is rolled up by letting it run up on the doctor, the press part being run slowly. If the old felt is to be used again, as is sometimes the case with a wet or first-press felt that is considered good enough to use as a second-press felt, or if it is to be washed, the old felt is taken out. The press frame, the ends of press rolls, the bearings, etc., are first cleaned; then the stretch roll is slackened, and the trough under press roll and the shower pipe is taken out. Now raise both ends of the upper press roll by means of the housings (levers), and pull out the old felt from between the rolls; lay the felt over the upper roll bearing; lower front end of upper roll, remove lower journal cap, and slip the yoke, or link, Fig. 72, over the journals of the upper and lower rolls; raise again on the housing, which will lift the lower journal from its bearing and permit the removal of the pedestal; wipe

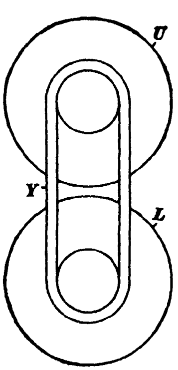


FIG. 72.—*L*, lower roll; *U*, upper roll; *Y*, yoke, or link.

journal and frame; take out lower side of old felt. The felt is now outside the press rolls, and it may be removed by lifting the ends of the felt rolls and slipping the felt over them.

195. Putting On a New Felt.—All grease and dirt must now be thoroughly removed from the frame, from the front ends of the rolls, and from any place the felt may touch. The new felt (endless) should be laid out full length on the clean tending floor. The felt is not laid out full width, but is gathered in folds until its width is reduced as much as possible. The loop of the felt at the press end is lifted, and the bottom part of the loop is passed under the end of the lower roll (both rolls being in the same position as when the old felt was removed), the upper part of the loop being held up and away. The lower roll bearing is then replaced, and the rolls are lowered until the bottom roll rests in its bearing; the upper roll is lowered a little more, but not touching the lower roll, and the yoke is removed. The top roll is now in the same position that it was before the yoke was put on, and the upper part of the loop of felt is slipped between the upper and lower rolls. The front end of the suction box is then removed from its bracket, and the felt is slipped over the end of it; the box is replaced, and the trough is replaced under the bottom roll. The inside rolls are then taken out of their front bearings—one at a time—and the felt is slipped over their ends; the shower pipe is replaced, and the felt is on. The top press roll is then lowered almost clear down, and the felt is gradually spread out to its full width by edging it out as the press is run slowly, allowing the felt to adjust itself to the machine.

196. Wetting the Felt.—When the felt is fully across the machine and the stretch roll is in place at its shortest stretch, the upper roll is lowered to place and the felt is wetted. A shower pipe across the machine should be used to wet the new felt gradually, care being taken that the felt is not moving until a steady, even stream of water is flowing over one roll across the full width of the felt. If the felt is a little slack, the slack should not be taken up immediately, because it will shrink greatly when the water soaks in. After the felt is well wetted and shrunken, the water can be shut off, and, if necessary, the slack can be taken up. The levers and weights are now put on, and all is ready for the paper.

197. Felt Marks.—Felt marks are the principal cause of many troubles that develop at the press part of the paper machine. The phrase "felt mark on the paper" is usually a misnomer. It is the impression made by the threads of the felt only in the case of old or too coarse felts, but is generally applied to the defects in the paper caused by the gradual filling in of spots in the felts meshes, which make the felt harder. The final result is the accumulation of stock and filler, which destroys the ability of the felt to press waste from the paper, and a blotch is formed. The water can escape when pressed out from the paper only by passing through the felt meshes at the side of these spots. The only remedy for this trouble is to clean the felt. When the felt is new, and if the lower rubber-covered roll be not too hard, a new felt should run satisfactorily for 48 hours without washing; but, as the felt ages, the time between washings is reduced, and felts finally have to be cleaned every 24 hours.

198. Washing the Felt.—Felts may be washed on the machine as follows, but felt washers or conditioners are recommended:

Remove all weights and levers; then slacken the felt by moving the stretch roll back as far as it will go. Turn a strong stream of clean water on the felt, and push the felt on itself, toward the center, until there is a clear space, about 2 feet wide, from both ends of the rolls. Allow the felt to run in the water this way until clean, or for about 45 minutes in the worst cases. When it is observed that the water being washed through the felt is coming away clear and clean, this indicates that the felt has been washed sufficiently. It may then be pulled flat by gradually drawing the edges to the front and back sides of the machine: keep the hands away from rolls; avoid danger. Before pulling out the felt, clear it of wrinkles; if it is a double-napped felt, turn it over, so the outside will be on the inside; this will insure that the felt wear uniformly on both sides; it will also give a longer running time between wash-ups, because the newly washed, dirty side of the felt is now on the inside, and the water pressed from the paper that leaves the felt from this side will carry off all the fine particles in the felt that may have remained after the felt washing. A weak solution of soap or soda ash is sometimes poured on the felt to assist in the cleaning. (See also Art. **190**.)

199. Care and Life of Felts.—A felt that is properly cared for should give 3 or 4 weeks of service on a fast news machine, which is very hard on felts because of its high speed and the quality of the stock. On the more slowly running book machines, there is no reason why a felt should not last much longer. The elimination of rolls running on the outside of the felt lengthens the life of the felt. Such rolls gather particles of fiber, forming lumps that dirty the felt.

200. General Rules for Washing Felts.—The temperature of the water should not exceed 120°F.; that is, it should not be hotter than one can comfortably bear when placing his hand in it, since a higher temperature injures the wool fibers.

The quantity of soap to be used varies with the amount of dirt to be removed from the felt and with the amount of size that has been used on the paper; however, enough soap should be used to give a good lather.

Use a good neutral soap that rinses out readily, and do not use strong alkalis, because alkalis containing caustic will dissolve wool fibers. There are brands of soap that have been specially prepared for this purpose, and one of these should be employed; the ordinary soap used about the mill is not satisfactory for felt-washing purposes.

If felts are washed in warm water, it is much better to reduce the temperature of the water gradually, while the felts are being rinsed, until the natural temperature of the water is reached; sudden changes in temperature change the original texture of the felt.

The felt should not be run in soap more than 20 minutes, and it should be rinsed only long enough to wash out the soap, say another 20 minutes. If a new soap is bought, try it out on a test strip of felt. Never use free acid on a felt.

201. Treatment of Felts and Jackets.—The stock should be watched carefully, and kept in a cool, absolutely dry place—moisture causes mildew and destruction of wool fibers. Felts and jackets should be kept in their original papers. Keep the felts clean; dirt injures them and attracts moths.

Use moth preventives freely and frequently; strong tar paper is good for this purpose. Flake naphthalene is the best preventive, but it evaporates and must be renewed. Sprinkle the felts

thoroughly with naphthalene and scatter it around the felt room.

The life of the felt depends on the condition of the machine. All press rolls should be turned with the proper crown to insure the best running conditions; press or felt rolls in bad condition, and rough suction-box covers, often greatly reduce length of service. All felts are subjected to great strains lengthwise, cylinder felts especially; hence, do not stretch the felts too tight. Felts on idle machines deteriorate almost as rapidly as when running. When shutting down, raise the top press roll and see that the air can reach the felt at every point, so it can

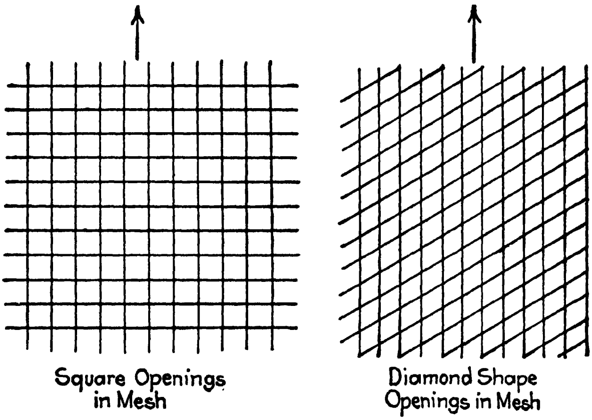


FIG. 73.

dry quickly and thus prevent mildewing. Carefully wash and dry all used felts, and keep them as clean as possible; their value depends on their condition.

Jackets should also be given reasonable treatment, notwithstanding that they are tough and strong. Stretching, shrinking, and tying down (lacing) ought to be done very carefully. The guard boards should not be set down tighter than is necessary.

202. Tension of Felts.—While it is very important to consider the tension of the felt, it is equally important that the seam be kept straight across the felt. The seam will run ahead on the ends or at the center, according to the condition of the rolls and the amount of crown used. When the crown is excessive, the seam will run ahead at the center. When the felt is unequally stressed in this manner, the meshes are partially closed, due to

the diamond shape that they are thereby forced to assume; this effect is illustrated in Fig. 73. The left-hand part of the figure shows the meshes (greatly exaggerated) when the felt is running properly, while right-hand part shows the meshes when distorted by excessive crowning or by having one side run ahead of the other.

When first put on, a felt can run under much less tension than later, and distortion of the weave has less effect, because the felt has enough nap to offset the extra pressure of the rolls. Under these conditions, the tension is not severe on the felt, and it would not then be absolutely necessary to correct for a crooked seam.

203. Influence of Tension on Width of Felts.—The extra width on new felts must not be trimmed off when they are new; it will be needed later, when the felts become thin with wear.

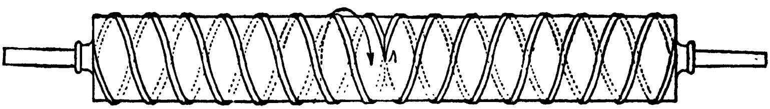


Fig. 74.

Felts should be ordered of correct width. When a felt has become worn, it is necessary to increase the tension on it, in order to open the meshes and thus more readily release the water. The width of a felt is controlled to a certain extent by its tension; when the tension is great, the felt naturally narrows, and it spreads when the tension is relieved.

204. Widening Felts.—When a felt has been narrowed by being stretched under the tension, it can be widened again by slacking the stretch roll and making one of the inside rolls (around which the felt wraps more than a quarter of a circle) into a worm. This latter operation is effected as shown in Fig. 74, by tacking a strip of felt to a wooden roll or by fastening a brass strip to the roll either by means of countersunk screws or by soldering it to a brass roll. Examination of Fig. 74 shows that the worm is double threaded and that it has right- and left-hand threads, the part to the right of *A* being left-handed and the part to the left of *A* being right-handed. As the felt moves in the direction of the arrow, the friction between it and the roll causes the roll to

turn also, and the threads tend to push the fibers away from the center A, which widens the felt.

205. Guiding the Felt.—To guide a felt, the end of the guide roll must be moved in the direction in which the felt is running, if it be desired to make it travel away from that end; but if the end of the roll is moved against the run of the felt, the felt will travel toward the end that was moved.

If the seam, or blue line, of a felt be not parallel with the axis of a felt roll, *i.e.*, if one end be ahead of the other, the end ahead can be brought back by increasing the stretch on whichever end of the line is ahead. The felt should be watched carefully whenever a roll is shifted, to see that its position is not altered. In cases where both ends of the seam are even (parallel with the axis of a felt roll) and the center is drawn back, add extra worming in the center of the roll, or at any place where the felt lags back.

206. Wrinkles and Slack Places.—If a straight wrinkle or lap appear in a new felt, and this often happens on wide machines (where the rolls are inclined to spring), the felt should be slack, to keep the wrinkle from running through the press. Slack up the tail and tighten up the head of the wrinkle, by moving the guide roll or stretch roll. Hot sizing poured on the wrinkle will make it disappear almost instantly, if the sizing be not allowed to go through the press again.

207. Analogy between Felts and Belts.—It is readily perceived that the felt acts like a belt, and it drives many rolls that would be undriven otherwise. These rolls all act as brakes, and to their action must be added the braking action of suction boxes. The place of greatest stress and strain is close to the driver, where the sum of all the holdbacks is concentrated. This naturally brings up for consideration the matter of type of bearings and the kind of lubrication used on journals of main press rolls and of the felt rolls driven by the felt.

208. Lubricating and Cooling Journals.—The journals of press and couch rolls (unless ball bearing) are water cooled. The castings that hold the bearing metal are hollow, and cold water is circulated through them.

Many methods of lubricating paper-machine bearings are in use, ranging from the open-top bearing, to the more pretentious bearings, which have a continuous supply of oil from a pump

or from a reservoir. Capillary bearings, which depend on a lamp wick to draw oil from a reservoir and wipe it on the journal, are also used with good results.

Paper-machine journals run at comparatively slow speeds; they should be amply large for the weights they support, and should have a cover over them, to keep out dirt and water and to keep in the oil or grease. A good millwright can often cure a bearing that gives trouble by cutting two helical grooves, say $\frac{1}{32}$ inch deep, on the journal, so as to compel the oil or grease to run around the journals until it reaches the place where the weight is carried. Bearings and lubrication are more fully discussed in Section 8, Vol. IV.

209. Length of Felts and Number of Rolls.—Many mill men think a long felt is better than a short one; but, in most cases, this is far from being true. If additional rolls accompany the longer felt, there is no gain. For instance, a 45-foot felt running around 9 rolls is no better than a 35-foot felt running around 7 rolls; in fact, it may be worse, on account of the extra hold-back of the two additional rolls, which evidently increases the total stress very near the driver. The life of a felt is materially increased by reducing the number of rolls that come in contact with the *outside* of the felt.

210. Pickup Felts.—If it is desired to have a felt pick up and carry away paper from another felt or from a wire, a smooth-surfaced felt that is air- and water-tight is needed. Such a felt must be woven of fine wool, and it should be napless. A pickup felt must be air-tight; therefore, it may be well filled with sizing. Trouble may often be experienced with a new pickup felt; if this occurs, fill up the felt with sizing, which is poured on until the pores are filled.

211. Weight of Felts.—There is very little information as to the weight of felts for different papers that can be accepted as a standard, because of the different ideas of various manufacturers of felts and paper. The weight of felts made by one manufacturer for a certain purpose might be quite different from the weight of felt made by another manufacturer for that identical purpose. One manufacturer of felts for news gets the best results from felts weighing 2 ounces per square foot, while another manufacturer cannot make a felt of this weight do the work

satisfactorily, and has to make the weight of his felts 2.25 to 2.50 ounces per square foot. Similarly, for third-press felts for news, some manufacturers get the best results from felts that weight 2.5 to 2.6 ounces per square foot, while others make their third-press felts weight 3 ounces or more per square foot. It is a question of durability and openness: given the same strength and durability, the lighter felt is more open and will give better results.

212. Qualities of Felts.—The first, second, and third felts for news and wrapping papers should have qualities about as follows, to obtain the best results:

First Felt.—The first felt should be of plain weave, made open, well napped, weighted about 2 ounces per square foot, and should be *woven* endless.

Second Felt.—The second felt should be the same as the first felt, except that it should be somewhat heavier: weave like

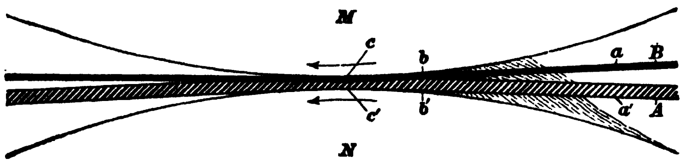


Fig. 75.

the first felt, but weight should be 2.25 ounces per square foot; this felt should also be woven endless. After use on the first press, the first felt is sometimes used as a second felt; but if the nap is well worn, the paper may be marked.

Third Felt.—For the third felt, a fine twill-weave press felt should be used; weight should be 2.75 ounces per square foot; it should be well napped.

213. The Function of the Felt.[1]—When a felt and sheet of paper pass between rolls, the following conditions exist as shown in this diagram. Felt A and the wet sheet of paper B, Fig. 75, pass between the rolls M and N. As particular points a and a', adjoining on sheet and felt, move into the nip of the rolls, a position b and b' is reached where water will begin to be squeezed out of the paper and felt. From this point on, the pressure becomes more and more concentrated, felt and sheet are com-

[1] From an article, illustrated with charts, by E. A. Rees, in *Pulp and Paper Mag. of Can.*, Feb. 1, 1923.

pressed closer together, and water is released from both until c and c' is reached, where two rolls approach the closest to each other and the greatest concentration of pressure is obtained. It will be noted, then, that felt and sheet pass progressively through rapidly changing pressure, and that the condition of equilibrium of this system under a gradient of pressure distribution will be determinied by the relations of many different factors such as:

(1) The pressure applied.
(2) Hardness of rolls.
(3) Radii of rolls.
(4) The speed of the sheet and felt.
(5) The time of contact.
(6) The resistance of the felt to the flow of water.

It will be seen in this diagram that the water passes from the sheet into the felt and through the felts throughout a gradient of pressure change. The ease with which water will flow through the felt at these different pressures is a very important factor in determining its efficiency as a water remover. The openness or porosity of the felt has always been recognized as a desirable property. And the resistance of the felt to the flow of water is important in determining not only the dryness of the sheet but also other effects that have to do with ease of operation, such as crushing and blowing.

It will be noted, however, that there are some discrepancies, as illustrated by several points that do not fall exactly on the line. The softness of the fabric also affects the concentration of the pressure upon the sheet of paper. Large variations in this property may so materially affect the concentration of pressure as to overbalance the porosity effect in different directions. For example, a hard, close felt might give a dryer sheet of paper than a soft, open felt, if the concentration of pressure is large enough to offset the difference in porosity.

It is also quite interesting to note that as the sheet and felt approach closer to points c and c', where the rolls are in closer contact, there is more and more resistance to the flow of water, because of the impervious roll beneath; and there is also the tendency for the revolving roll to carry the water back into the nip. As the water is released farther back in the nip, then, there is more and more necessity for water to permeate through the felt in the direction contrary to its motion. This lateral or back-

ward porosity through a gradient of pressure change is also a factor in determining the efficiency of the felt as a water remover.

214. Felts for Particular Papers.—When manufacturing fine writings and bonds, the character of the stock is such that it is difficult to free it from water. These felts are of decidedly closer texture, and are made of finer yarns than the common wet felts used for newsprint or wrapping papers. While a newsprint felt is of a plain weave, the felts for fine papers are generally of a complex weave, the nature of which is to cause it to act as a compact carrier and as a perfect filter. A fair estimate of the weights per square foot for this grade is 1.46 to 1.64 ounces. The second felt will be heavier and much closer, weighing from 1.56 to 2.68 ounces per square foot. The felt for the last press, if three are used, is very thick, and it has a very heavy nap. It must be borne in mind that the felt must permit a perfect filtering of the water from the sheet; otherwise, the cost of production will be high on account of the excessive steam consumption for drying.

The felt used on a machine making the general type of tissue papers is a plain-woven, rather close-mesh fabric, with little or no nap on the top side. In fact, many mills prefer that a felt for making tissue paper be singed on both sides, to keep the fibers in the sheet from adhering to the felt surface (picking up). Singeing keeps the nap that is formed by the felting process from being drawn over the mesh of the felt by the suction box or roll. If the under side of the mesh is clogged by wool, the felt will soon fill up and get dirty, causing broke and many other difficulties.

It is needless to state that the quality of the wool used in all these felts is a matter for the closest attention of the felt manufacturer.

DETAILS OF PRESS ROLLS

215. Construction of Press Rolls.—In the days when paper machines were so narrow that the attendant could almost reach across them, the lower press rolls were brass cased and the upper press rolls were made of wood. The nip, that is, the area of contact between the rolls, was very narrow, not only because of the absence of the resiliency and softness of the rubber covering but also because of the small diameter of the rolls. A little

thought will make it obvious that the area of contact between two rolls of large diameter will be greater than when the rolls are of small diameter. Now the quantity of water pressed out of the paper is directly proportional to the pressure per square inch of area of contact between the rolls; in other words, the efficient working of a press is measured by the *specific pressure* of the rolls (total pressure divided by the area of contact) and not by the total pressure. Pressure is frequently expressed as so many pounds per inch of width of the machine.

The custom of covering the lower press rolls with rubber results from, first, the necessity for an automatic adjustment of the line of contact by an elastic medium, to correct for faulty crowning under differing conditions; also, second, from the necessity of prolonging the life of the felt.

216. Crowning the Roll.—Any beam will deflect (bend) more or less between its supports, because of its own weight; and the deflection will be increased by any other load that the beam may support. The amount of this deflection will depend upon the material of which the beam is made, the diameter of the beam (if round), and its length between supports. But there will be a certain amount of deflection always; and if the beam is straight and horizontal it will sag in the middle under its own weight and under a uniform load across the beam. A roll in a paper machine acts like a beam, and its own weight plus the pull exerted uniformly across it by the felt causes it to sag in the middle. It follows, then, when two rolls are ground to true cylindrical surfaces and are placed one on top of the other, both being horizontal (or nearly so) and supported at their ends (their journals), that they will not touch at their middle points. This condition is proved by the fact that light passes between the rolls; and it can be corrected by crowning the lower roll (which naturally sags the most) just enough to insure perfect contact from end to end. A roll is said to be **crowned** when it is larger in diameter at the middle than at the ends and gradually tapers from the middle to the ends. The greater the diameter of the roll in proportion to its length the stiffer it is, and the smaller is the amount of sag (deflection).

But there are other considerations to be taken into account when choosing press rolls of large or small diameter for a paper

machine. If the observer stand alongside a paper machine and note the escape of water at the nip of the press rolls, he will soon be impressed with the fact that the faster the machine runs the less chance the water has to escape, because the tendency of the upcoming surface of the lower press roll is continually to carry the water back toward the nip; and the larger the diameter of the lower press roll the worse this condition becomes. Attempts have been made to place water deflectors close to the nip, to lead this water away, and in this service they have been invariably successful. In practice, many accidents have occurred through their use, such as the deflectors' getting into the nip, etc., with the consequence that these deflectors are seldom used. If a press roll is made too small in diameter and is running at high speed, it is almost impossible for the machine tender to pick off the paper.

217. Effects of Rubber-Covered Rolls.—When the papers being made on the machine differ in weight and quality, the amount of pressure on the top roll is varied by shifting the weight on the levers that operate on the journals of the top roll. Since the amount of deflection of the roll varies directly as this pressure varies, the initial crowning of the rolls is not suited to every condition of working. The maximum efficient action of the crown is possible only between comparatively narrow limits of variation in position of the weights. The use of rubber covering largely increases the limits of effective working pressure of a particular crown, as compared with the same crown on a similar roll that is not rubber covered. The rubber, in adjusting itself to working conditions, largely increases the width of contact between the two rolls; this increases the area of contact and decreases the specific pressure, which lessens the dewatering action of the press. In brief, the rubber covering of a press roll corrects for faulty crown and preserves the felts; but it lets the paper go to the dryers containing a larger proportion of moisture than if a plain roll were used. The softer the rubber the more pronounced is this last effect.

Although having greater dewatering power, hard rubber or metal rolls possess disadvantages. Felt meshes fill and become hard much more quickly, and this causes breaks at the press due to felt marks and to small lumps becoming crushed while passing

through the press; time is lost because of frequent washing of felts; the life of the felt is shortened because of frequent washing and the lack of cushion in hard-rubber-covered rolls.

Felts taken from a press whose rolls are covered with hard rubber are seldom really worn out. They have lost just enough of the nap to make them thinner and too hard to give good results with hard rolls, since thin, napless felts frequently mark the paper. Two weeks, or 12 running days of 24 hours each, is about the limit of running time for felts on hard rolls. Further, when hard rolls are used, it is necessary to wash felts at least once every 24 hours.

If rubber of the proper hardness (density) be used, the running time of felts between washings will be largely increased, and the life of the felts will therefore be greatly lengthened; felts may then be used for 4 or 5 weeks, or even longer.

If there is a disadvantage in using soft rolls, it is because they need more frequent grinding; a soft roll should be ground about once in every 2 months. However, a roll covered as stated will easily give 3 to 4 years' run, if properly used and not allowed to corrugate.

218. Troubles Peculiar to Rubber Coverings.—A rubber covering corrugates or gets uneven in lines parallel to the axis of the roll, if the rubber is subjected to too much pressure. This effect is generally caused by the roll's being crowned either too much or too little, and by the machine tender's being obliged to carry too much weight on his levers in order to get an even pressure between the rolls across the machine. The longer life of a soft-rubber-covered roll will more than counterbalance the expense of grinding the roll, when this is compared with the loss of felts and paper production that are inevitable consequences of the use of hard rolls. Hard rolls have also a further disadvantage, in that they have a decided tendency to check, and these *check marks*, or small cracks, must be ground out as often, nearly, as the soft roll requires grinding to remove its corrugations.

The density (hardness) of rubber-covered rolls that give satisfactory service should be measured with a plastometer, sclerometer, or similar instrument; the results thus obtained should be noted, and should be insisted upon when drawing up specifications for use in ordering new rolls.

219. Crown of Rolls.—In general, it is probable that too much crown is given the lower roll, the elastic quality of the rubber covering being depended upon to counterbalance any irregularities in dressing the roll.

The following table gives, approximately, the proper crown for lower press rolls when they are being ground; and the values here specified are sufficiently exact for all practical purposes, unless the design of the roll itself varies extremely from general shop practice. The table gives the crowning for rubber-covered rolls for the first and second press; for the third press, reduce the values 5%. Thus, for a 20-inch roll for a first or second press having 180 inches length of face, the crowning is (see table) 0.104 inch; for a third press, this should be $0.104 \times (1 - 0.05) = 0.104 \times 0.95 = 0.0988$, say 0.099 inch. The figures here given for the crowning indicate how much larger the diameter of the roll should be at the middle than at the ends. It is assumed that the rolls are made with cast-iron bodies and that they are of standard construction.

THE FELT ROLLS

220. Construction and Sizes.—The shells of the felt rolls should be of such quality and thickness that, for any specified diameter, they may have sufficient strength to withstand the strains induced by the continuous reversal of stress, which is due to the turning of the roll in the grip of the pulling felt. Consider, for instance, a felt roll 8 inches in diameter, to be used on a high-speed news machine. Such a roll may revolve on its own axis say 300 times in a minute, giving 600 reversals of stress in that time. Some day, this action must crystallize the metal at the point of greatest bending moment, just as a wire can be broken by continually bending it back and forth. The life of these rolls depends on the selection of good material, proper thickness and diameter of shell, and they should be in dynamic balance. Use as few rolls as possible on the outside of the felt; each is a dirt catcher, and each deposits dirt on the paper side of the felt.

221. Proper Balancing of Rolls.—A roll is in **static balance** (neutral equilibrium) when it can be placed with its axis horizontal, its journals resting on knife edges, and have no tendency to roll or turn. A roll is in **dynamic balance** when it turns steadily

CROWNING OF STANDARD PRESS ROLLS IN THOUSANDTHS OF AN INCH

Diameter in inches	Face of roll in inches																						
	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250
6	6	19	43	78	132	210																		
8	3	8	18	33	55	90	140	200																
10	1	4	9	17	30	47	72	102	140	180	236													
12	1	2	5	10	17	27	42	59	81	105	137	175	215											
14	..	1	4	7	11	17	26	37	51	66	86	110	137	168	206									
16	..	1	3	5	8	12	18	26	36	46	60	77	96	118	144	172	202							
18	..	1	2	4	6	9	13	18	25	34	43	54	67	83	101	121	143	169	197	228				
20	..	..	1	3	4	6	9	13	18	24	31	39	49	60	73	87	104	122	142	165	189	217		
22	..	..	1	2	3	5	7	10	14	19	24	30	37	46	56	67	79	94	110	127	145	166	190	215
24	..	..	..	1	3	4	6	8	11	15	19	24	30	37	45	54	64	75	87	100	114	128	146	165
26	..	..	..	1	2	3	4	6	9	12	15	19	25	31	37	44	51	60	70	81	93	107	122	138
28	..	..	..	1	2	2	3	5	7	9	12	15	19	23	28	33	40	47	55	64	73	83	96	108
30	..	..	..	..	1	2	3	4	6	7	10	12	15	19	23	27	32	38	44	51	59	68	77	87
32	..	..	..	..	1	1	2	3	5	6	8	10	12	16	19	22	26	31	36	42	48	55	68	77
34	..	..	..	..	...	1	2	3	4	5	6	8	10	13	16	18	22	26	30	35	40	46	52	59
36	..	..	..	..	...	...	1	2	3	4	5	7	8	11	14	16	19	22	25	29	33	38	42	49

in its bearings at high speed. A roll may be in static balance and not in dynamic balance, as will now be explained. Referring to Fig. 76, suppose *A*, *B*, *C*, and *D* are weights placed inside the shell. If *A* and *B* are equal in weight and shape, are situated equally distant from the axis of the roll, and are placed on opposite sides, but at opposite ends, the roll will be in static balance. If *C* and *D* are of different weights and shapes, *C* being lighter than *D* and farther from the axis, *D* may be so placed that the roll will still be in static balance. If the roll is turning swiftly in its bearings, weights *A* and *B* not being directly opposite each other will impart to the roll a wobbly motion. Since *C* and *D* are not of equal weight and are situated at unequal distances from the axis of revolution, the centrifugal force exerted by *D* and the section of the shell adjacent to *D* is not quite the same as that exerted by *C* and the section of the shell adjacent to *C*. At very high speeds, the difference between these two values for

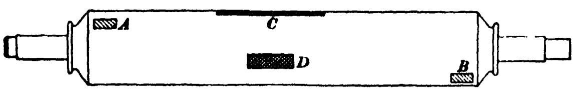


FIG. 76.

centrifugal force becomes considerable, and it puts additional stresses and strains on the roll and on the bearings. The matter of dynamic balance becomes especially important in connection with Fourdrinier table rolls.

THE DRAW

222. Definition of Draw.—The **draw** is the tension (stretch) on the paper as it passes from one section of the machine to another. There must be a certain tension, or draw, between couch rolls and the first press rolls, between the press sections, the last press and dryers, between dryers and calender, and between calender and reels. The term is especially applicable to the wet end, where the paper gets about all of its longitudinal stretching, which is caused by each press running more rapidly than the one that precedes it.

223. Correcting Faulty Draws.—If the paper is too tight between the couch rolls and the first press, and between the presses, it may get narrow, even though the deckles have not

been moved. To correct this condition, bring the various presses more nearly to a uniform speed by speeding up the slow ones or slowing down the fast ones. The trouble may have arisen through changing the weights on one press, or because of a change in character of stock. Many papermakers are too afraid of a slack draw between presses; a slack draw is a good thing, provided it is not loose enough to crease the paper. The less a paper is stretched on the machine the stronger it is. The control of the draw has been improved by the development of the electric drive, described later.

Sometimes a paper machine is not quite in alinement, and the paper may show a tendency to travel to one side, even arriving at the calenders 4 inches or more to one side. This fault can be corrected by putting a leading roll with the proper 'cant' (obliqueness) between the last press and the dryers, thus guiding the paper back again to the center of the dryer rolls.

224. Operating Variables on Press Part.—As the wet sheet of paper leaves the couch roll and goes on through the several press sections, it is further processed to remove additional water and make the sheet more compact. The variables in the press section have a definite effect on the physical properties of the finished sheet. Different pressures on the various presses may alter the finish, density, tensile and bursting strengths, as well as the folding endurance of the sheet. The draw between sections may also affect the tensile strength, porosity, and other sheet characteristics to a marked degree. Many of the press-section variables are included in the following list:

1. Draw between wire and first press.
2. Angle at which sheet leaves the wire.
3. Wetness of sheet leaving the wire.
4. Material used for the cover of the press rolls.
5. Density, or plastometer reading, of rubber cover on press rolls.
6. Diameter of top press roll.
7. Offset of top press roll.
8. Pressure per inch of face of top press roll.
9. Crown of press rolls.
10. Number and size of holes in suction-press roll.
11. Setting of suction box of bottom suction-press roll.

12. Type of felt used on first-press roll.
13. Type of felt stretch on first press (also on the other presses).
14. Type of press-roll doctor.
15. Amount of draw between first and second presses.
16. Adjustment of draw between presses.
17. Type and character of second- and third-press felts.
18. Material and density of smoothing-press rolls.
19. Diameter of smoothing-press rolls.
20. Pressure of smoothing-press rolls.

PAPERMAKING MACHINES

(PART 2)

EXAMINATION QUESTIONS

1. Explain how the paper is transferred from the wire to the felt.

2. What factors affect the percentage of solids in the paper as it comes to the press part?

3. What factors affect the percentage of solids in paper going from the press part?

4. About what is the limiting percentage of solids obtainable in paper by pressing in the press part of the paper machine?

5. (*a*) What are the nature and purpose of the press-roll doctor? (*b*) Why should it be oscillated?

6. (*a*) How is the paper transferred from the first press to the second? (*b*) from the last press to the dryers?

7. Why is the paper reversed at the last press?

8. Explain the purpose and operation of the felt guide roll.

9. (*a*) Describe a felt suction box. (*b*) What is the advantage of using it?

10. Referring to Figs. 62 and 64 and Arts. **174** and **176**, suppose the various lever arms were carefully measured and found to have the following lengths: $d_1 = 42$ in., $d_2 = 5\frac{3}{8}$ in., $d_3 = 11\frac{5}{8}$ in., $d_4 = 3\frac{3}{4}$ in., $d_5 = 44\frac{1}{4}$ in., and $d_6 = 25\frac{7}{8}$ in.; (*a*) what is the velocity ratio of the entire combination? (*b*) If a weight of 56 lb. be placed on the end of each of the levers *G*, what will be the pressure theoretically exerted by the press roll due to these weights?

$$Ans. \begin{cases} (a)\ 41.425+ \\ (b)\ 4640 \text{ lb.} \end{cases}$$

11. (*a*) Name some advantages of a suction-press roll. (*b*) Describe how it acts.

12. Describe in detail the method of putting on a new felt.

13. What precautions should be taken when putting on a felt?

14. (*a*) What is usually meant by 'felt mark'? (*b*) How is it remedied?

15. Mention some points on the care of felts.

16. What is the effect of tension on felts?

17. What is meant by crowning a roll? Why is it necessary? How much crown is required for a roll 160 in. wide and 24 in. in diameter?

18. What is the effect of incorrect crown of the press roll on the felt?

19. Compare the effects of small hard- and soft-rubber rolls.

20. Explain: (*a*) the term 'draw'; (*b*) the danger in a slack draw; (*c*) in a tight draw.

SECTION 1

PAPERMAKING MACHINES

(PART 3)

THE DRYER PART

PRELIMINARY

225. Passing Sheet from Last Press to Dryer Section.—After the paper goes through the last press, all water has been removed that is possible by mechanical means, and the removal of any additional moisture from the sheet must be accomplished by the **dryers.**

Some machines are equipped with a **smoothing press** between the last press and the dryers, which further presses the sheet while still in a wet condition. This type of press is used on high-grade printing papers, such as book grades, and to some extent on news machines.

The paper at this point will contain 60% to 70% of water. In this condition, it requires less pressure to smooth out the inequalities in the surface that are due to impressions of the wire mesh and the weave of the felts than when the paper is dry and hard. It is also possible to print what is practically a *water-mark* by impressing steel type on the soft paper. Other designs may be produced in a similar manner. In some papers, the impressions of the felt and the bulk of the sheet are to be retained for special effects. This can be secured, and the paper flattened to a uniform thickness, by means of a properly adjusted pair of smoothing (or impression) rolls, no felt being used between these rolls.

226. The Smoothing Rolls.—Fig. 77 shows a pair of **smoothing rolls,** A and B, which are mounted on the dryer frame at the end nearest the last press rolls K of the press part. The top press

roll A is rubber covered, while the lower press roll B has a gun-metal or bronze shell. These rolls may be so made that they can be reversed; that is, the rubber-covered roll can be placed on the bottom and the metal-covered roll on the top. The required difference in hardness may also be obtained by using two rubber rolls of different degrees of hardness. The paper P is shown as passing over the top of the upper roll, back through the nip between the two rolls, and from there to the first lower dryer D, against which it is held by the dryer felt F. The ductor X guides the paper into the nip of the smoothing press,

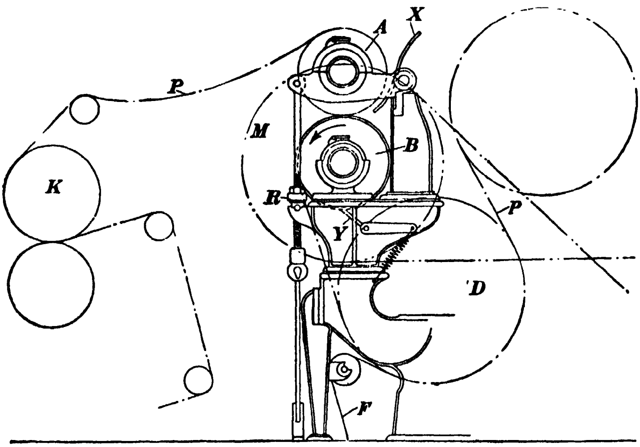


FIG. 77.

and the doctor Y scrapes the paper off the lower smoothing roll, so it will drop between the dryer felt and the first lower dryer D. If desired, the paper can be passed directly from the last press K through the nip between the two smoothing rolls, or the paper may be conducted to the dryers without passing through the smoothing press. On some machines the smoothing press is placed near the middle of the dryer section.

Each succeeding unit of the paper machine runs a little faster than the preceding one, to prevent the paper from running back on a roll and catching on a doctor. This causes a *draw* (see Art. **222**) between successive units, which requires careful attention and is a frequent cause of breaks. Adjustment is made by shifting a belt on a cone gear of a mechanical drive, etc., or by

means to be described later in connection with an electrical drive.

227. Crowning the Roll.—The rubber roll is compressible and resilient, thus assuring a perfect contact across the machine, if accurately crowned and covered with rubber of the proper density. The correct crowns to be used as a guide in grinding these rolls have been given in Part 2 of this Section. Since the design of a press roll varies in accordance with the ideas of different paper-machine manufacturers, the crowns there specified may not quite suit all makes of rolls. However, for the first grinding, they are accurate enough to work satisfactorily within the range of control given by the weights and levers.

228. Finish of Paper.—A **glazed finish** is obtained by crushing the surface of dry paper after a superficial dampening or sweating, and a **smooth finish,** by the use of pressure rolls or breaker calenders in the dryer nest. M. G. or machine glazed paper is made on a Yankee machine, which is fully described in Part 5.

229. Definition of Ductor.—There is sometimes a misunderstanding as to the meaning of the words 'ductor' and 'doctor,' as used in the industry. In this textbook, the term **ductor** refers to any device for leading (conducting) the paper into a nip. The word **doctor,** on the other hand, refers to a scraper that is used to keep the surface of a roll clean.

A TYPICAL DRYER PART

230. Purpose of the Dryers.—The **dryer section** of a paper machine consists of a set of cast-iron cylinders, connected and driven by a train of gears, and heated by steam, the steam so used being exhaust or low-pressure steam. Most machines have a dryer felt or canvas, to support and carry the paper and hold it in contact with the cylinders, which are usually called the **dryers.** Heat from the steam is conducted through the dryer shells to the paper and evaporates the moisture (water) in the paper. The resulting vapor is absorbed by an air current, and is carried outside the building. In passing over the dryers, the moisture content of the paper will be reduced from an original state of 60%–70% to 6%–8% on leaving the dryers. This means an average removal of about 2 pounds of water per pound of finished paper.

It is necessary to provide means for removing the moisture-laden air from the room, and for removing from the dryers the water that results from the condensation of the steam. Methods for accomplishing this will be described later.

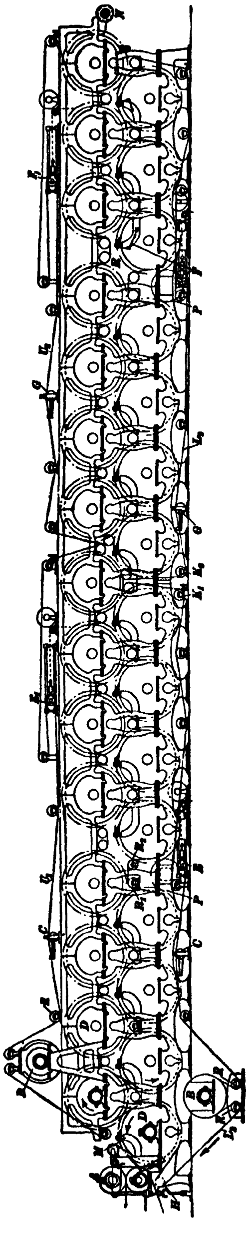


Fig. 78.

231. The Two Parts of the Dryer Section.—Fig. 78 shows a typical dryer part. It consists of a smoothing press *A*, 30 48-inch (diameter) dryers *D*, and 2 36-inch felt dryers *B*. The paper passes through the smoothing press, and the dryers are driven by gears at the back. There are two upper felts and two lower felts. The first upper felt and the first lower felt partially enwrap the first 8 (left-hand) upper dryers and the first 8 lower dryers, respectively. The first upper felt and first lower felt have each a felt dryer *B*, an automatic guide roll *C* (see also Fig. 83), and an automatic stretch roll *E* (see also Fig. 84). The second upper felt and the second lower felt partially enwrap the 7 upper dryers and the 7 lower dryers, respectively, at the right end of the nest (section): they both have an automatic guide roll *G* and an automatic stretcher *F*, but no felt dryer. The felt on the first-felt dryer is more efficiently placed as shown, because the dryer felts are damper at this point than at any other place in the dryer nest, and the dried felt immediately takes up paper again. The reader is advised to take a pointer that will not mark the diagram, Fig. 78 (a match or nail file will do), and follow, first, the run of the felts throughout the nest; then follow, second, the run of the paper. Follow the run of the felts first,

beginning with the lower felt, because it first receives the paper. The circles in solid lines represent dryers, the larger ones in dotted lines are the gears. There may be as many as eight felts on some machines.

232. Course of the Felts.—Beginning with the felt roll *H*, below the smoothing press, follow the lower felt throughout its entire length until the starting point is again reached. This felt (canvas) wraps around approximately one-third of the circumference of the first (left-hand) dryer *D*. The felt touches about one-half of the surface of each dryer after the first; it passes under the first four dryers and over the first four felt rolls (not counting the first roll *H*), reaching at this point the two rolls R_1 and R_2, over the pinion *P*. As the felt comes up from under the eighth lower dryer, over the felt roll, and down on its return journey, it first passes around a hand guide roll K_1. This last is simply a felt roll, one journal of which rests in bearings on a bracket, which can be moved by means of a hand screw; the hand screw itself is fixed, and it works in a bracket base, as in a nut, to move the bracket in the desired direction. The hand guide roll may be located elsewhere; in fact, it is a principle that the lead of a felt to a guide roll should be as long as possible.

The dryer felt then travels back until it comes to the automatic stretch roll *E*, which is more fully described later. This stretch roll automatically takes in the slack of the dryer felt by means of weights, which are suspended on a carriage, the chain holding the weights passing over a pulley that is between the stretch roll and the weights.

From the automatic stretch roll the felt passes over an automatic guide roll *C*, which is more fully described later. This guide roll has bearings on brackets that swing on pivoted levers. When the felt travels too much to one side, it pushes against a finger on the lever at that side, which pushes the bearing forward and forces the felt to travel toward the other side. To obtain sensitive automatic action of the guide, the distance between the nearest roll back of the guide roll and the guide roll itself should be at least 6 feet, and preferably much greater, the best distance being determined by local conditions.

After leaving the automatic guide roll, the felt comes to the **felt dryer** *B*. Concerning the value of a felt dryer, there is a

difference of opinion. Drying the felt is supposed to keep the felt from rotting, and it thus makes the felt last longer. The felt dryers also tend to keep the felt more uniform, and they help to prevent uneven drying conditions. These dryers may be steam-heated cylinders like those used for drying paper, though smaller in diameter, or they may be the more recent type of perforated drum. In the latter style, hot air is blown into the drum, and, passing through and drying the felt.

233. Course of the Paper.—As the paper leaves the smoothing press, it drops between the felt and the first lower dryer *D*, Fig. 78, passes under the dryer, and comes up on the other side, and a little wad is tucked between the felt and the first upper dryer. After passing the first upper dryer, it is taken by the back tender and passed to the entering side of the second lower dryer; it is thus passed under each lower dryer and up over the next succeeding upper dryer until it leaves the last upper dryer and is thrown up into the top nip of the calenders; sometimes it is thrown over the top roll, depending on which side of the stack the first nip is. The spring roll *N* automatically takes care of variations in tension.

234. Back-Tender Ropes.—The **back-tender ropes,** or **Sheehan rope carrier,** is a part of the standard equipment on modern high-speed news, kraft, and other machines. This consists of a pair of parallel endless ropes, which run in grooved flanges on the front side of each dryer roll that carries the *lead strip,* or **tail,** of the paper over the dryers. The two ropes run together, just as they come onto the baby dryer. The tail is deftly lifted from the last press felt and dropped into the nip of the pair of ropes as they travel down around the baby or first dryer. The tail is held tightly between the two ropes, and is carried to the dry end of the machine; as soon as the tail is started down the dryers, the sheet is widened on the wire by the squirt, and the complete sheet is then going through the machine. As the tail goes over the last dryer the ropes separate, and a jet of compressed air helps to clear the ropes of paper. The back-tender ropes are usually $\frac{3}{8}$ to $\frac{1}{2}$ inch in diameter, and are made of high-grade cotton. The return ropes travel back over the top of the dryers in sets of sheaves or flanged pulleys, and they are kept at the correct tension by an automatic take-up.

On paper machines operating at over 1000 ft. per min., the rope carrier is necessary for the safe and economical handling from the wet to the dry end of the machine. At these speeds it is almost physically impossible for the back tender to take the paper over the dryers by hand.

235. Dryer Doctors.—It is customary to have a dryer doctor on the first bottom dryer to assist in putting the sheet through the dryer section. This is similar in principle to the doctor used on the presses shown in Fig. 65. The doctor blade is usually a thin steel strip, or of a composition material that does not excessively wear the face of the dryer. The doctor also serves to keep the dryer face free of fuzz, slugs, and other foreign material that might break down the sheet or cause a defect in the paper. Anything that prevents close contact of paper and dryer reduces the efficiency of heat transfer.

In making some grades of paper, there is a tendency for the fuzz to pick up on the first few wet-end dryers. Similar doctors can be applied to the bottom dryers, so that the face of the dryer can be kept smooth and clean. It is more difficult to apply a doctor to the top dryers, and this is seldom done. As a rule, dryer doctors are not used the entire length of the dryer section, but only on the first quarter or third of the bottom dryers. However, on machines making special grades of paper, all the bottom dryers may have doctors.

236. Steam Joints and Driving Gear.—Fig. 79 is a cross-sectional view of the dryer nest shown in Fig. 78. The felt rolls *R*, the felt dryers *B*, the top and bottom dryers *D*, *D*, all have the same reference letters as the corresponding parts in Fig. 78. The steam joints *M*, shown connected to the back hollow journals *J* of the dryers, are piped to two pipe headers *S* and *E*. The larger pipe *S* supplies steam to the dryer, while the smaller pipe *E* is a drain that carries away the water of condensation. The steam joints are described later.

The gears that drive the dryers are shown at *G*, and a platform or walkway for the operators is shown at *K*. In this case, the felt dryers *B* are driven by the felt, and they have no gears; this is good practice, but the bearings must be kept in first-class condition.

237. Dryers to Be Kept Free from Water, Air, and Grease.—It is essential, in order to dry paper well and evenly across the sheet, that the dryers be kept free from water, air, and grease. An air valve or small pet cock is sometimes placed on the front head of the dryer, often on the steam joint, and may be opened when the dryers are warming up. It helps to get rid of the

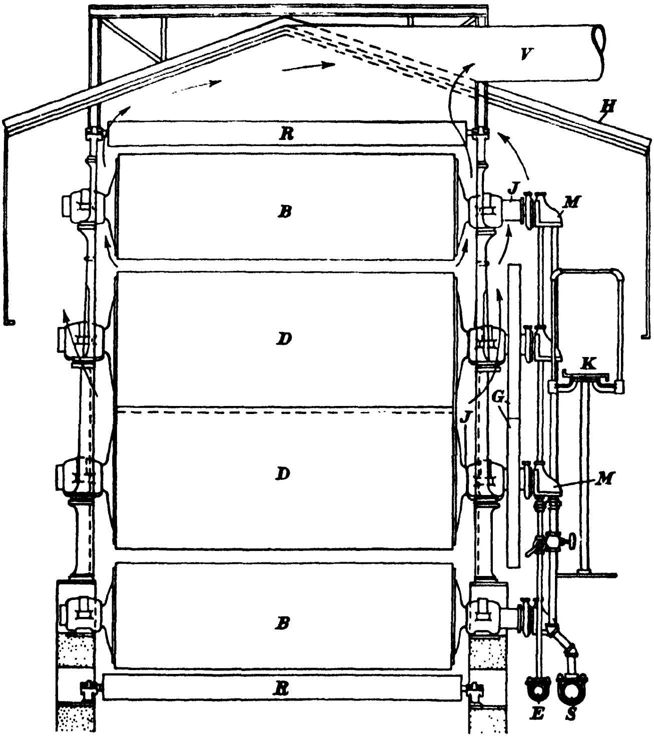


FIG. 79.

accumulation of air, which acts as a blanket, keeping heat from getting to the dryer shell. The water that collects in the dryer, because of the condensation of the steam, is a good non-conductor of heat and also acts as a blanket; it is removed by either a siphon or a dipper, as will be described later. Some heating systems are designed to sweep the air out of the dryers by rapid circulation of steam.

The dryer part should be started turning over before any steam is admitted into the dryers, in order to prevent the unequal

strains that are produced when hot steam enters a cold dryer. The top of the dryer may heat and expand more than the bottom, and thus the dryer tends to get out of shape.

Oil acts as a coating, on the inside of the dryer, preventing transfer of heat; it may also get into the steam from the lubrication of the engine piston, and should be caught in an oil separator. If it gets into the dryer, it may be removed by treatment with a hot solution of soda ash.

SOME TYPES OF DRYERS

238. The Minton Vacuum Dryer.[1]—This type of dryer is a unit comprising a series of standard dryers, together with dryer felts, felt carrying rolls, automatic and hand guide rolls for the

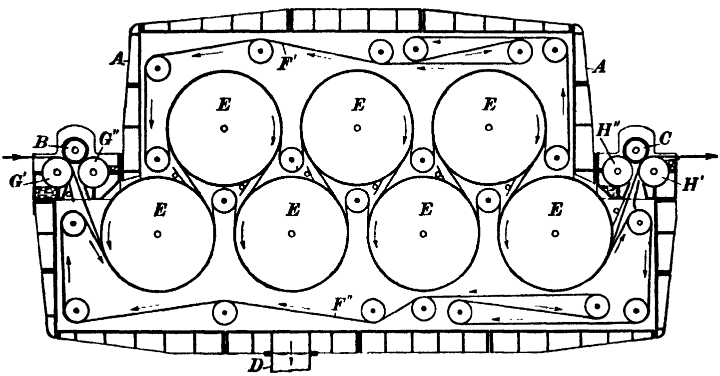


FIG. 80.

felts, and automatic stretch rolls, all of which may be exactly like the same equipment for a standard dryer nest. The entire drying unit is enclosed in a vacuum chamber. At the front end *A* of the chamber, Fig. 80, there is a *seal B*, which allows the wet paper to enter but does not allow the air to do so. Similarly, at the rear, or dry, end of the unit, there is another seal *C*, which allows the dry paper to pass out of the vacuum chamber. The outgoing seal *C* may also be in an inverted position, allowing the paper to fall by gravity to it from the last dryer; this type of seal is used on high-speed machines. Connected at the bottom of the chamber, at *D*, is a condenser, of the surface, jet, or baro-

[1] For full description, see *J. Eng. Inst. of Can.*, January, 1928, or *Pulp and Paper Mag. of Canada*, Jan. 19 and 26, 1928.

metric type, and connected to this condenser is a dry vacuum pump.

When the paper is put through the dryers, the air is first pumped out of the chamber. Normally, the condenser and pump keep the vacuum in this chamber at 28 inches of mercury. Then the wet paper is passed into the ingoing seal and around the dryers *E*. The dry paper passes through the outgoing seal and from there to the calender or reel. The course of the paper through the dryer unit is indicated by arrows, the heavy lines representing the edge of the felts or paper and felts.

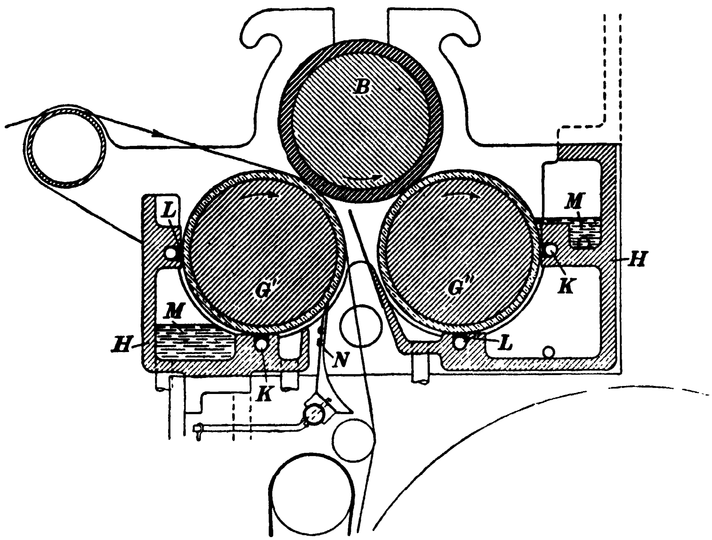


FIG. 81.

239. The Seals.—The seals consist of two bronze-covered rolls G' and G'', Fig. 81 (which shows an ingoing seal), with special sealing rings on their ends, to prevent air leakage next the casing. On top of these rolls runs a rubber-covered roll *B*, with similar sealing rings on its ends. The cast-iron housing for these three rolls is shown, and also the grooves in which are placed rubber tubes *K*, over which are rubber sealing strips *L*. Water or air pressure is applied to the inside of the tubes to hold the sealing strips against the bronze-covered rolls. Water is supplied in troughs *M* as a sealing medium, and it also acts to lubricate the rubber sealing strips *L*; two of these strips are used on each of the

bronze rolls. One strip acts to limit the amount of water that is allowed to leak into the vacuum chamber, while the other acts to wipe the surface of the roll dry before it reaches the paper. The small amount of water that leaks past the sealing strips into the vacuum chamber is caught and used in the condenser as cooling water, or it can be pumped to waste.

The paper passes into the chamber between the bronze-covered roll G' and the rubber-covered roll B. The surface of the rubber-covered roll is soft enough to allow the paper to pass, but it effectively seals the chamber against the entrance of air. In the same manner, the paper passes out of the outgoing seal. The vacuum pulls down the rubber-covered roll, making it press tight against the two bronze-covered rolls. Air cannot leak into the vacuum chamber past the sealing strips, because, to do so, it must displace the sealing water ahead of it; this it cannot do, as a constant supply of water is maintained at this opening.

240. Passing the Paper.—On slow-speed vacuum dryers, the paper is usually looped over a stiff piece of cardboard, about 8 inches wide and 4 feet long, called a *go-devil*, and the paper and cardboard are both fed into the ingoing seal. Ductors on the sealing rolls, as N, Fig. 81, and on the dryers, together with the dryer felt, automatically guide the paper and cardboard through the dryer and out through the outgoing seal. On higher-speed machines, such as news machines, the streamer of paper is thrown or blown into the nip of the bronze-covered roll and the rubber-covered roll of the ingoing seal, and from there it is passed from dryer to dryer by means of air jets.

241. Theoretical Considerations.—In a vacuum of 28 inches of mercury, water boils at a temperature of approximately 100°F., while in the atmosphere at sea level, it boils at 212°F. There is thus a large temperature difference between the surface of the dryer and the evaporating temperature, with the result that only about half the number of dryers are required in a vacuum dryer, thus shortening the distance from the third press to the calender very greatly. The dryers are surrounded by a high vacuum, which acts like a thermos bottle, preventing radiation of heat, except to material coming into direct contact with the surface of the dryers. Thus, heat is given off more directly to the paper, and a very high heat-transmission efficiency is obtained.

No vapors are given off to the machine room; since they are all taken to the condenser and condensed. The dry vacuum pump has only to be large enough to take care of the air leaks, which are slight, and the entrained air in the incoming sheet of wet paper.

242. Control of Drying.—The drying of the paper can be closely controlled: weather conditions do not affect the operation. The drying conditions are determined by the operator; and he can vary the vacuum or the steam pressure in the dryers to suit the condition of the paper coming from the last wet press. The steam consumption of a vacuum dryer is somewhat less than that of an atmospheric dryer of the same capacity, thus reducing the cost of drying paper.

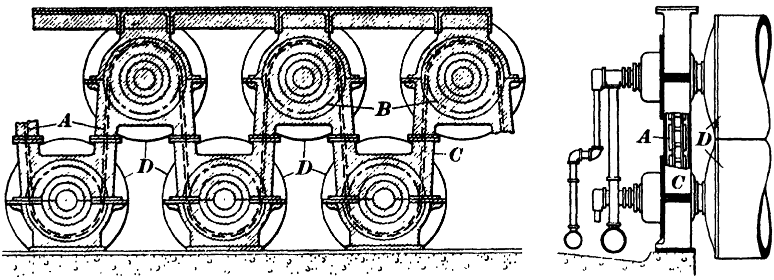


FIG. 82.

243. The Electric Dryer.—A system of drying paper by electricity has been developed, and it was installed on a small paper machine. The paper was carried on Fourdrinier wires through a heating chamber that was kept at the proper temperature by controlled open heating elements. Since the possible operating speeds were relatively slow, this system was not easily adapted to the high-speed modern type of paper machine, and it was not commercially adopted in the industry.

244. The Chain Drive for Dryers.—The *gear drive* is the conventional type of drive on the large majority of paper machines. The *silent chain drive* has also been developed, and it is used on a number of modern kraft and newsprint machines. This latter method of driving the dryers, Fig. 82, simplifies the design of the back side of the machine and makes it more open, a very desirable feature of high-speed machines. The endless roller chain *A*

drives the sprockets *B* attached to each dryer, and returns under the machine. The chain runs in a casing *C* and in oil, to give smooth operation. This type of drive has some advantages over gears, but more care must be taken when the machine is started up or shut down, so that undue strains will not be placed on the chains or the bearings of the dryers.

245. Antifriction Bearings.—Roller and ball bearings have been adopted on many pieces of equipment in the paper mills. On the paper machine, the antifriction bearing is used fairly successfully on the table rolls and wire rolls, as well as on the breast roll, couch roll, and press rolls. The housings for these roller bearings have been so designed that they will keep out the water, which is very injurious to a roller bearing. The method of lubricating bearings in this service has been worked out so that there is a minimum of bearing troubles in most operations.

The problem of using roller bearings on the dryer section is somewhat more complex. A pair of antifriction bearings and housings on a dryer must be so designed that they will carry the full load of the dryer with a liberal factor of safety. These bearings must also be so designed that they will take care of expansion and contraction caused by heating up or cooling down the dryer shell. On a standard three-roll news machine, the expansion between bearings will be nearly $\frac{1}{2}$ in. when brought from a cold start up to the high temperature of operating conditions. This necessitates that the front-side bearing allow for this expansion, in order that the back-side bearing be not obliged to withstand undue stresses.

Both bearings must provide for deflection of the dryer and consequent weaving motion of the dryer bearings. This is especially important after a dryer has been allowed to cool off for a period of 12 to 24 hours. The bearings on dryers must also be designed to withstand continued high-temperature conditions, and this is particularly true of the back-side bearings. The lubrication of roller bearings is extremely important, and it is generally recognized that the *circulating oil system* is the most satisfactory method of lubricating the paper machine. A circulating system, either gravity or forced feed, will keep the temperature of the bearings down to a safe point, provided the oil volume is sufficient. The collecting of paper dust or other

foreign materials makes it necessary to put this oil through a filter, centrifuge, or other type of cleaning equipment, so that clean oil will be going through the system at all times. It is also important that this oil be cooled to a reasonable degree before being returned to the system.

Dryer bearings have sometimes failed because it has not been recognized that a dryer bearing and housing must be able to take care of the conditions herein mentioned; namely, (*a*) expansion and contraction; (*b*) high-temperature conditions, particularly in the back-side bearings; (*c*) deflection and weaving motion; (*d*) proper design of housing so oil can freely circulate without collecting foreign material.

DRYER-PART DETAILS

DRYER FELTS AND FELT ROLLS

246. Function of the Dryer Felt.—The dryer felt acts as a carrier of the paper through the dryers; it also acts to hold the sheet against the heated dryer cylinders, which produces more even drying and helps to give an even surface and a more compact sheet.

247. Types of Felts.—A majority of the felts used are made of a fine grade canvas, specially woven, and of different weights and weaves. They are made to suit the machine or the grade of paper being made, and to work most economically. The felts may be *single, duplex, or triplex woven,* and are of different weights, strengths, and thicknesses. The heavier felts may be required on wide fast machines, where operating conditions are exacting; but any felt must be sufficiently open or porous to allow the vapor to go through and also maintain uniform conditions. The single-weave, or lighter, felts tend to lengthen out (stretch) more than the heavier ones shortly after they are installed on the machine. At the same time they become narrower; therefore, dryer felts are ordered several inches wider than the face of the dryer, so as fully to cover it when they get older and 'narrow up.'

The woolen dryer felt is sometimes used on machines making special grades of paper that require a smooth surface. However, on account of their extra cost, this type of felt has a limited field.

248. The Asbestos Felt.—This newer type of felt is being used successfully by many mills. It is a combination of cotton and asbestos threads, so woven that the felt will have sufficient strength to function satisfactorily on the machine. Since the felt fails or wears out principally because the cotton threads gradually deteriorate, or 'burn,' by reason of continual contact with the heated dryer, the partial substitution of asbestos for cotton threads gives the felt longer life. This felt also maintains its porosity better than the cotton felt when it becomes old. However, the asbestos felt has less strength than the cotton felt of equal weight per square foot, and the seams are not quite so substantial. The asbestos felt costs much more than the cotton felt; hence, it must give more service in order to compensate for the extra cost.

249. Position of Felts.—Most of the modern paper machines use four felts on the dryer section; *viz.*, the first top, first bottom, second top, and second bottom, starting from the wet end of the machine. Some of the older and small machines use only one top and one bottom felt. The path of each felt is indicated in Fig. 78, and each has its own system of dryers, felt, guide, and stretch rolls.

250. Automatic Guide for Dryer Felts.—Since the felt is sewn or riveted so as to make it endless, it acts similar to a wide belt, but is much more sensitive to a weaving motion. To make it run true and keep on the machine, the felt guide must function quickly and accurately; otherwise, if a felt runs off the machine, it may badly damage the dryer part, as well as spoil the felt. A typical automatic guide is shown in Fig. 83. One of the felt carrying rolls *A* (usually the last return roll) has a cone *C* attached to the front side of the roll. Cone *C* does not normally rotate; but it will turn with the rotation of the felt roll if the edge of the moving dryer felt *D* starts to ride up onto it. When this occurs, the cable *B* winds up and pulls the lever *K*, which actuates and moves the journal of the guide roll *R* toward the cone. When one end of the guide roll is thus pulled out of parallel with the other guide rolls, it acts on the felt to run it back to its correct position on the machine. The normal pull of the B–K mechanism is balanced by the spring *S*.

Many of the older machines were equipped with the *finger* type of felt guides. A rod is located parallel to and a short distance ahead of the guide roll. This rod is just above the felt and has a 'finger,' or vertical metal palm, projecting downward on each side, so as just to clear the edge of the moving felt. If the felt weaves or goes to one side of the machine, it contacts the finger, which acts on the levers of the felt-roll bearing and moves in the correct position to run the felt back to where it belongs.

In order for a felt to move straight, *the axis of any roll that it touches must be at right angles to the direction of travel of the felt.* If such is not the case, *the felt will always come to the end of the roll*

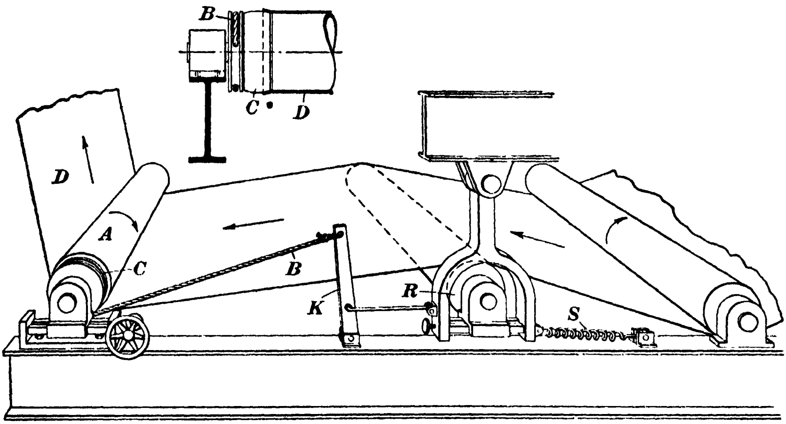


Fig. 83.

it touches first. If, therefore, *the front-side end of the guide roll be moved in the same direction that the felt is traveling, the felt will go to the back side of the machine,* because it touches the back end of the roll first. And if the *front end of the guide roll be moved against the direction of felt travel, the felt will come to the front end,* since it strikes the front end of the roll first.

STRETCHING AND TIGHTENING FELTS

251. Automatic Stretcher for Dryer Felts.—An automatic dryer-felt stretcher is shown in Fig. 84. The felt *F* is wrapped halfway around a felt roll *R*, whose journal runs in a bearing that is carried by trolley wheels *C*, a similar journal, bearing, etc., being on the other end of the roll. The trolleys *C* on either side

of the machine are caused to move simultaneously by the shaft *S*, which extends across the machine. Therefore, when pulleys *A* and *B* on one side turn, the corresponding pulleys on the other side turn also; and they turn the same distance at the same time, because all these pulleys are keyed to the shaft *S*. This device keeps one end of the stretcher roll from being pulled ahead of the other and thus shifting the felt.

The weights *W*, which are hung on chains *D* that grip the chain slots on pulleys *A* on both sides of the machine, tend to turn shaft *S* with a force proportional to the number of weights hung on these chains; and they are generally so calculated as to give a pull of about 2 pounds per inch of width of felt. The pull of the weights on pulleys *A* tends to turn shaft *S*, and also pulleys *B*, which are at the ends of the shaft in line with the trolleys *C*. The chains on the trolleys are furnished with turn buckles *K*, to

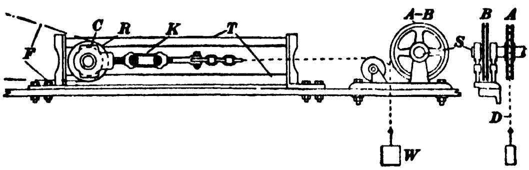


FIG. 84.

permit of accurate adjustment. The chains are also attached to the rims of pulleys *B*; so that, as these pulleys tend to turn, the chains pull on trolleys *C* and, therefore, on the felt that is wrapped around the felt roll carried by trolleys *C*. The trolleys move easily on the guide rails *T*; and when the pull of the felt slackens, the weights automatically pull on the trolleys until the proper tension is obtained.

252. Felts Should Be Given Correct Tension.—The automatic felt tightener should be watched to observe its condition. If in good condition, this will be indicated by a constant movement in one direction or the other. If the tightener always remains still, it may be out of order, may require lubricating, or may be gripped between the rails. A felt that is too tight or too loose will spoil paper very quickly, causing uneven drying and cockling; since the felt rolls may be pulled out of line, if the felt is too tight, or the felt may be hanging loose because the slack is not being taken up.

The old-fashioned felt tightener did not have sufficient capacity to take up all the slack in a long felt. This type of stretcher is still used on dryer felts, and it will take up a certain amount of slack; but it is necessary to install also a hand-stretching device similar in design to the hand felt stretcher.

253. The Dancing Roll.—A very sensitive and direct-acting stretcher for a dryer felt is a **dancing roll,** which is more common on European machines; this rests in a loop of the felt, the entire weight being carried by the felt. Brackets are bolted to the dryer frames, and the bearings of the roll are free to move up and down the vertical slots in the brackets. The 'return' felt rolls, over which the felt runs to make the loop, are supported in brackets bolted to the slotted brackets. This is a good type of dryer-felt stretcher; but its principal failing is that it is limited in its range of action by the height of the vertical slots in the brackets. Another drawback is that one end may get into a higher position than the other, which would cause the roll to act like a guide roll and shift the felt to one side of the machine.

254. Amount of Stretching and Shrinking.—The purpose of the automatic stretcher is to take up the slack of the felt when the paper leaves the machine for any cause, as a break at the wet end or a shut-down. A 60-yard felt will shrink 3 feet at the very least when it is wet, and it lengthens a like amount in a few minutes when the paper is off the dryers. On the average, a brand-new felt will shrink and stretch considerably more than this, some felts as much as 6 feet. The old-style swing stretcher did not give enough leeway to take care of this shrinkage; and if the felt were tightened up sufficiently to run straight and guide properly, it was too tight when it became wet.

After putting on a new felt, it should be weighted down until it is fairly tight; and it should be run around a few minutes before passing the paper over it, to enable it to straighten. After the felt is perfectly straight and the paper is passed over the machine, the machine tender should watch the automatic stretcher, to see that it is easing up as the felt gets shorter. If the felt is getting crooked, it is a sign that there are not enough weights, for a slack felt will almost always run crooked. When a good automatic stretcher is in proper working order and is well adjusted, the

stretch roll should tremble—move back and forth slightly—every time the dryer-felt seam passes over it.

255. Guiding Felts by the Stretch Roll.—Some stretchers stretch with the felt, *i.e.*, move in the direction of travel of the felt; others move in the opposite direction.

To show how the stretch roll may be used to guide the felt, consider Fig. 85, in which either *A* or *B* may be the stretch roll; or if *A* is the stretch roll, then *B* is the reef, or fixed, roll, and vice versa. If the felt is traveling in the direction indicated by the arrows, *T* is the tight side, and *S* is the slack side. If the

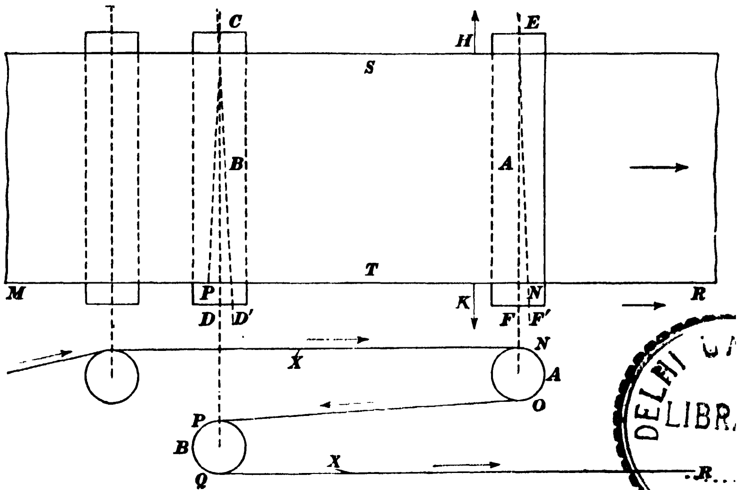


FIG. 85.

roll *A* is shifted toward the tight side, so its axis *EF* makes an angle *FEF'* with its former position, the felt will go to the slack side, in the direction of the arrow *H*; but if *B* is shifted toward the tight side, so its axis *CD* makes an angle *DCD'* with its former position, the felt will go to the tight side in the direction of the arrow *K*. The roll *A* acts as stated in Art. **250,** while *B* checks in the opposite direction because the felt travels in the opposite direction.

The dryer-felt stretcher is one of the most important parts of the machine to know how to handle. If, for any reason, the felt gets beyond control and gets partly off the machine, moving the stretcher 2 inches out of line will guide the felt more quickly and surely than all the carrying rolls together.

The wet felts or woolen felts will always go to the slack side of the stretcher, except, very rarely, in the case of a new felt, which may go to the tight side for a few hours.

STEAM SUPPLY AND CONTROL

256. Steam-Supply Systems.—A majority of the older type paper machines used the reciprocating type of engine to provide power, and the exhaust was used to dry the paper. In this case, the volume of steam, as well as the pressures, are regulated by a supplemental supply of direct or higher pressure steam, which is introduced into the line through a reducing and control valve. Some machines have a steam turbine as a prime mover, which is used as a direct driving unit. The exhaust steam is used for drying, and the piping arrangement is similar in principle to the reciprocating engine drive. In some cases, where the paper machine is equipped with the electric drive, a turbo-generator set makes the direct current for driving the paper machine. The exhaust is piped to the machine in a manner similar to the equipment just mentioned, and a supplemental supply of high-pressure steam is provided for make-up. In other modern systems where the machine is electrically driven, a supply of live steam is used to dry the paper. This goes through pressure-reducing and control valves, in order to maintain the proper pressures and temperatures for drying.

A typical arrangement of a steam-supply system for a machine using live steam for drying is illustrated in Fig. 86, in which nine dryers and a baby dryer are shown. In this arrangement the steam circulates through the dry-end dryers, and the last six wet-end dryers are used as condensing dryers. The steam first circulates through the dry end of the machine and then goes to dryers 1 to 6, inclusive, which function principally as a condensing unit, although the wet sheet is gradually warmed up as it passes over this section. The main supply of steam enters through the principal steam header *A*. The steam pipe *B* is a smaller size return header. The piping and valves to each dryer, as well as the condensate return, are indicated at *C*. The steam pressure is regulated by a differential pressure regulator *H* and the tank shown at *D*, which is an auxiliary return header coming from the dryers. The condensate removed from the

dryers goes through the siphon pipes *G* and tank *D* and down to the receiving tank *E*, from whence it is pumped back to the hot well or the boiler house by the pump *F*. The 'flash' or excess steam will go back through the return header *B*. The various control valves, pressure gauges, automatic controls, and auxiliary lines are indicated in the figure.

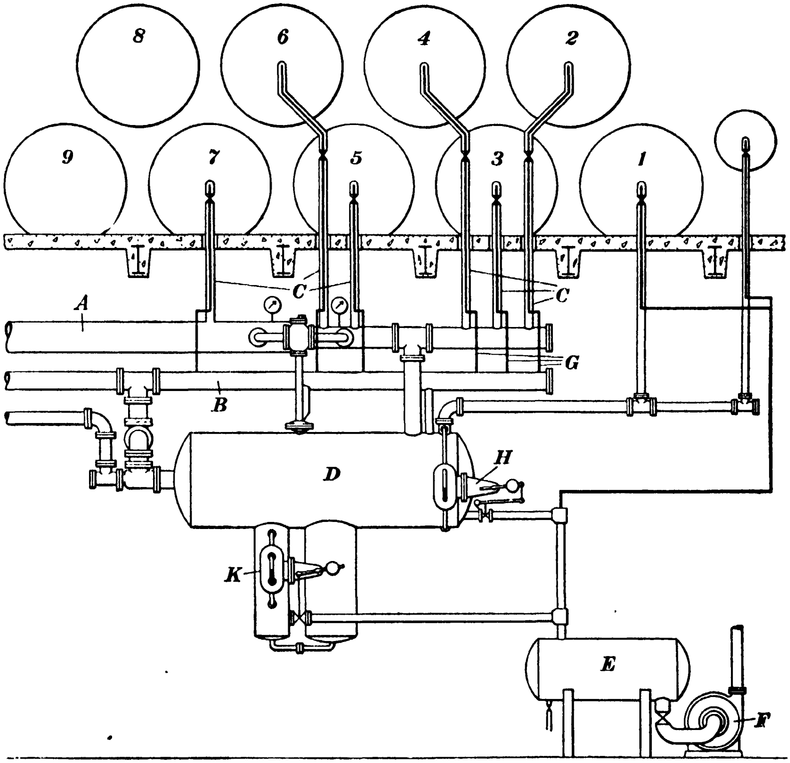


FIG. 86.

257. Temperature Control of Drying.—Although pressure control for the steam supply to the dryer part of the paper machine is largely employed, temperature control has been adopted by many modern mills. Since a 1-pound pressure differential is equivalent to between 2° and 3° temperature difference, it is possible with proper equipment to maintain more uniform conditions with temperature than with pressure control. With a satisfactory automatic temperature control, the regulation should

be as close as 1° to 2°F. When a break occurs on the paper machine and the paper is off the dryers, there is a momentary increase in dryer temperature; but this corrects itself, so that the dryer is at the proper temperature when the sheet is ready to go back over the dryers again. This is important, because overheated dryers mean too dry paper, whereas underheated dryers cause the paper to run too wet: either condition will result in defective paper and lost production.

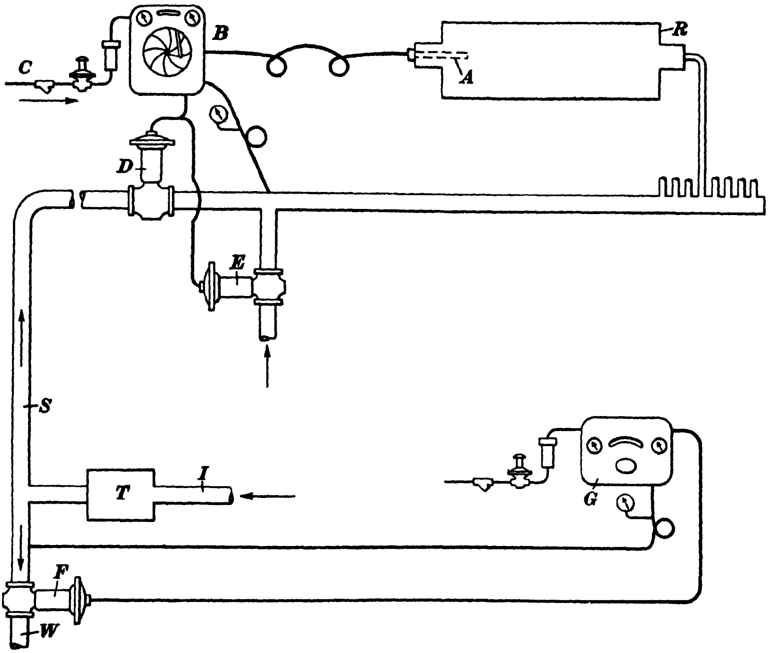


FIG. 87.

The temperature element of the instrument is in the front end of one of the dryers, usually about one-third of the way down the dryer section, starting from the wet end. A change in temperature actuates the temperature-controlling unit, which will either increase or decrease the air pressure and close or open the steam-control valve. This is illustrated diagrammatically in Fig. 87, for a dryer installation using both exhaust and live steam. A change in temperature at bulb *A* in dryer *R* alters the temperature control *B*, which can be set at any desired

temperature. The auxiliary air supply *C* passes through a combination reducing and relief valve and actuates the control valves located in the steam-supply lines at points *D* (exhaust) and *E* (live-steam make-up), and the supply of steam is immediately increased or reduced, to bring the temperature back to the correct setting on the temperature control *B*. If valves *D* and *E* do not reduce the steam sufficiently, control valve *F* will open, and the steam will go to the hot well *W* or to the atmosphere. Valve *F* is regulated by the pressure-control *G*, which is set at a predetermined figure. *I* is the steam inlet to the engine or turbine *T*, the exhaust of which passes through pipes *S* to the dryers.

The temperature control has a *chart* that makes a visible and permanent record. This record is of value to the operator: it

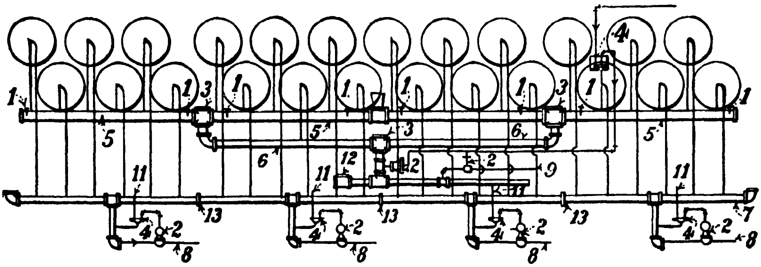


FIG. 88.

enables him to see how his machine is running, and to compare operating conditions on different days.

258. Pressure Control of Drying.—The conventional method of controlling the steam to the dryers is illustrated in Fig. 88. The steam header 1 is divided into two sections by the distributing valves 3, and is further sub-divided by similar valves to enable the right proportion of steam to go to each section. The exhaust steam comes from the engine and goes through valves 2, which are automatically controlled by a diaphragm that is actuated by steam pressure. If the pressure in the dryers drops because of a faster rate of condensation of the steam, valve 2 will open and more steam will go into the system. If the steam pressure in the dryers becomes too high, this pressure diaphragm will close the valve and reduce the steam input. Valves 2 and 3 can be adjusted by the operator to obtain the desired drying conditions.

The water-removal system is divided into four sections, in order to keep the pressure in the water-header sections below that of the steam pressure. There are three flanges at 13 that are blanks, and this separates the different sections. With such an arrangement it is possible to change the pressure in any one of the sections without disturbing the conditions on the other part of the dryer section.

259. Tension Control of Drying.—As the sheet of paper is carried down the dryers, it gradually loses its moisture: it also

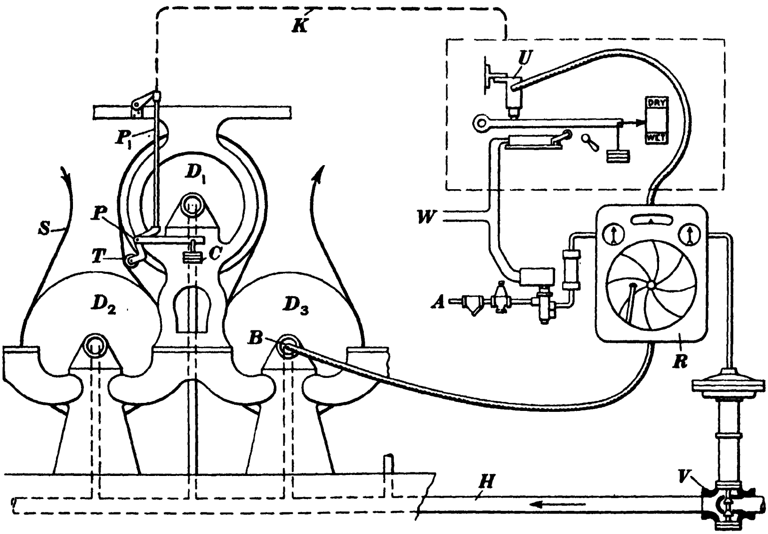


Fig. 89.

contracts, and is drawn tighter between the successive dryer cylinders. This principle of contraction is used to control the amount of steam furnished for drying. At a point about two-thirds down the dryer section, a tension roll is installed. This is illustrated in Fig. 89 at *T*. The paper *S* goes over the tension roll *T* in its travel between two adjacent dryers, as D_1 and D_2. The tension roll is adjusted to a certain position for a definite moisture per cent in the sheet by means of counterweights *C*. If the position of this tension roll changes, caused by shrinkage of the paper as it becomes dryer, or the reverse action if wetter, a series of levers *P* and P_1, and controls, will actuate the steam valve to increase or decrease the steam supply to the dryer

section. The movement of the tension roll by the expansion or contraction of the sheet is an effective method to control the drying process, provided the control mechanism that varies the volume of steam functions correctly. On some machines a cable *K* is connected with the controlling steam valve that increases or shuts off the steam supply. Other installations have combined the sheet tension with the temperature-control unit that varies the steam supply.

The general piping layout will vary somewhat, depending to some extent on whether live steam, exhaust steam, or a combination of the two is used to supply the steam for drying. In Fig. 89, *A* is the air supply; *B* is the bulb temperature-control unit; *C* is the tension balance on roll *T*; *H* is the dryer steam header; *R* is the recording controller; *U* is the tension-control unit; *V* is the steam-inlet control valve; *W* is the wiring connection.

260. Control of Steam by the Verigraph.—The **verigraph** is an instrument that indicates and controls the amount of moisture in the sheet as it comes to the reel. This instrument is tied in with the steam-supply system, and it can be set for any predetermined moisture content in the sheet. If the sheet becomes too dry, this equipment, through a series of contacts and valves, reduces the volume of steam to the dryers and brings the moisture in the sheet back to the desired per cent.

261. Condensate Removal Systems.—The continuous and effective removal of the condensate steam in the dryers is essential to good dryer operation. In general, the *condensate removal system* refers to the siphons, traps, piping, receivers, and pumps required to force the water out of the dryers and back to the hot-water system, where it goes to the boiler house and is re-used. The particular method of furnishing steam to one or more sections of the dryers is often considered a part of the system, though this is not actually the case, since the supply of steam to the dryers usually is a distinct and separate part of the paper-drying problem.

There are a large number of so-called condensate removal systems, but, in general, these may be classified as follows: (*a*) the trap system; (*b*) the circulating system. The theory of the **trap system** is that each dryer functions as a condensing unit, and that the individual traps on each dryer will provide for the

removal of condensate without loss of steam. The **circulating system,** or what is sometimes known as the **blow-through system,** is so arranged that the steam will circulate through a group of dryers, usually at the wet end of the machine, which function as a condensing unit. This latter group of three to six dryers is generally provided with one or more steam traps, separators, or other similar equipment, whereby the steam will not leave the dryers before condensing.

The principal difference in the various types of condensate removal systems is in the different types of steam traps, arrangement of steam and condensate piping, location of the separators, and other similar features: some of these will be discussed later.

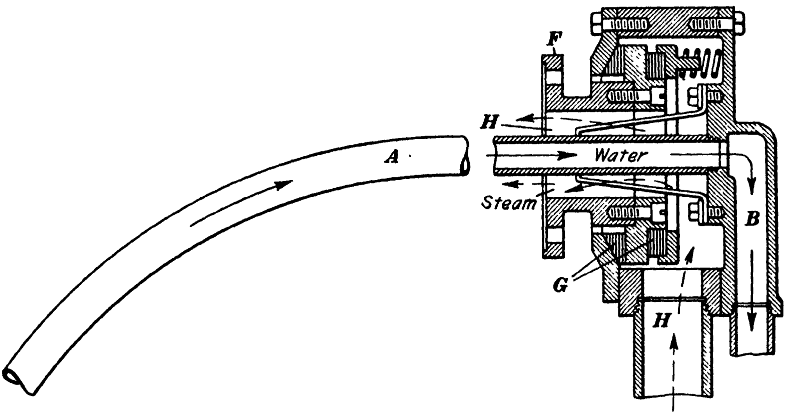


Fig. 90.

262. Siphons and Dippers.—The principal medium used to pick up the water from the revolving dryer is the so-called **siphon type,** which is shown in Fig. 90. The steam inlet is shown at *H*; and as the steam goes into the dryer *F*, a pressure is produced which forces the condensate up through the siphon pipe *A*, through the steam joints, and then through the outlet pipe *B*, which goes to the hot-water system. The steam seals *G* permit the dryer flange fitting *F* to rotate without leakage of steam. Usually a vacuum is also produced by a pump in the hot-water line, so that the siphon pipe *A* will function in the event that the pressure in the dryer is not sufficient to lift the column of hot water up through the siphon. The siphon remains stationary while the dryer revolves, and the lower end should

clear the bottom of the dryer about one-half inch. Some siphon pipes have a special collector or horizontal opening, which tends to pick up the water more rapidly because of the larger longitudinal area. It is possible to alter the position of the siphon on modern machines so that, instead of being vertical with the end in the lowest position of the dryer, it is at the point in the revolving dryer where the water is deepest. As long as the bottom end is under water, the steam pressure on the surface of the water forces it out of the dryer, whether revolving or not.

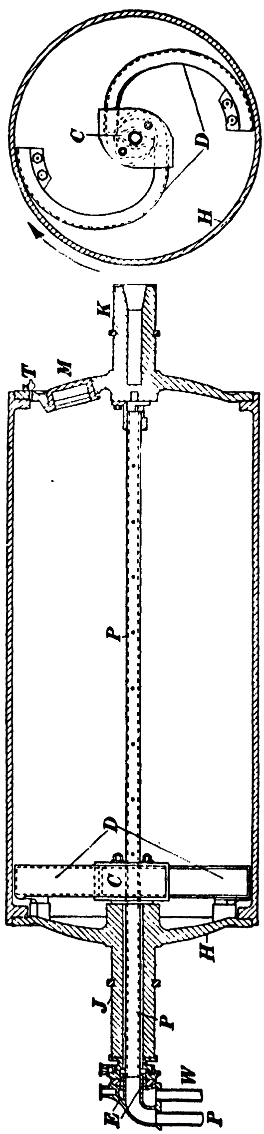


Fig. 91.

The **dryer dipper** is also used to remove water from the dryer. This is better adapted to slow-running paper machines; it is not ordinarily used on high-speed news, kraft, and similar modern machines. A dryer fitted with a so-called *double dipper* is shown in Fig. 91. These dippers are attached to the dryer head and revolve with the dryer. As the dryer turns the water enters the open end of the dippers, flows along the channel or pipe *D*, and to the center receiving chamber *C*. From here it flows out through the journal *J*, and then passes through *E* to the pipe *W*, which takes it back to the hot-water system. Some dippers are attached to the dryer shell, but both function in a similar manner. This method of removing condensate is a combination of scooping and gravity flow, which occurs as the dipper is lifted from a lower position to a higher point as the dryer revolves. Dippers do not work, of course, when the dryer is stationary. Steam enters through pipe *P*.

263. Action of Water in Dryer.—At the slower speeds of 500 or 600 ft. per min., the condensate steam (water) in the dryers remains at the lowest point in the dryer, since at these speeds the centrifugal force does not counteract the force of gravity to any marked extent. As the dryer speed increases, the friction and centrifugal force cause the water to climb the up-running side of the dryer, and it is the usual practice to turn the siphon away from its vertical position so that the end will be in the deepest part of the water. At speeds up to 800 or 900 ft. per min. and with a condensate-removal system that functions properly, there is little tendency for the water to be carried around the inside surface of the dryer by centrifugal action. At the higher speeds of 1100 to 1300 ft. per min. there is a definite centrifugal action, and the water in the dryer will form a thin film fairly evenly over the inside shell of the dryer. As this layer of water becomes thicker and heavier, it will be broken up and removed by the siphon; hence, if the dryer has a siphon functioning properly, only a thin layer of water is around the inside surface at any time.

If the water is not continuously removed from the dryers, the amount of condensate in any dryer having water in it will build up a heavy load, and it will be evident because of the increased power load on the drive of the dryer section. If the machine has a sectional electric drive, an increased dryer load can often be traced to the fact that several of the siphons are not functioning properly and that several dryers contain excessive amounts of water. The siphons and drives should be tested out every week end, when the paper machine is down, to ascertain whether the equipment is operating in the proper manner. A dryer full of water also gives trouble because it cannot give up its heat as rapidly as it should and, therefore, does not do its drying job properly.

264. Injector Circulation.—This type of apparatus is a combination of steam supply and water removal. It employs the principle of the injector, sometimes used for feeding water to boilers, condensers, and similar applications. The injector is based on the venturi throat principle, which is a restricted area in a pipe that so increases the velocity of the fluid passing through it as to create a suction. As applied to a paper machine,

each dryer has a circulator, which receives its steam from the regular source and is placed in the condensate line of each dryer. If there is any flash steam from this type of circulator, it may be

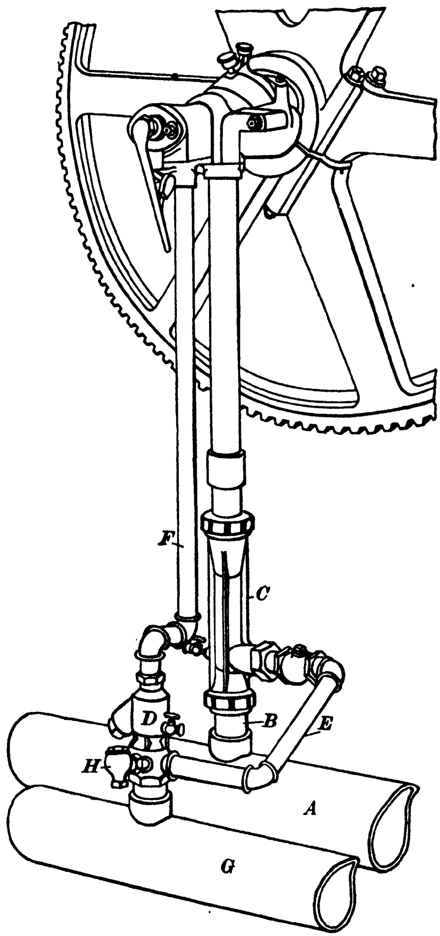


Fig. 92.

put through a steam separator or similar device and returned to the system. This particular type of dryer circulator is shown in Fig. 92, in which pipe *A* is the steam-supply system, which passes through the venturi circulator *C*. As the steam goes through the venturi throat, the velocity induces the suction, and

exerts a pull on the siphon pipe through pipe *E* and steam separator *D*. This suction is transmitted through pipe *F*, which pulls the water through the steam joint of the dryer. When the water in the dryer has been removed, the seal at the end of the siphon breaks, and the steam will go into the dryer. As the water again builds up, it will be drawn out as before. Thus the action is usually intermittent in removing water from the dryers.

265. Steam Traps.—The primary function of the steam trap is to permit the water to return to the hot-water system and, at the same time, prevent the steam from leaving the dryer header or other place where it is desired. Traps are required on any dryer system, and their size and number depend largely on the steam supply, condensate return, and other steam piping.

In the dryer system illustrated in Fig. 86 and described in Art. **256**, the principal trap is on the group of condensing dryers near the wet end of the machine. Other traps are also required on the system; but in this particular type of steam-supply and condensate-removal system there is a minimum number of traps. This is generally considered to be an advantage, because traps require considerable care in order to keep them working properly. If traps get out of order, the whole system sometimes causes trouble, and the drying may be uneven and result in lost production.

Some drying systems have individual traps on each dryer. This has some advantage in that it is possible to determine just how each dryer is functioning, since the individual traps usually have a sight glass, thus enabling the operator to see if water is being continuously removed from the dryer. On the other hand, a large number of traps on the paper machine requires considerable attention in order to keep them functioning properly. They must be tested out every week and often changed, which usually results in high maintenance costs. Consequently, a majority of dryer systems use as few traps as possible to maintain good steam circulation, satisfactory drying conditions, and continuous removal of condensate from the dryers.

266. Bell Type of Trap.—Two general types of traps are in common use: the bell, or inverted bucket, type, and the tilting type. There are a number of variations of these, but the fundamental principles of steam traps are common to all.

The **bell type** consists of a chamber in which is suspended a bell-shaped unit *A*, Fig. 93. The steam and condensate enter at *B*, under the bell, which gradually rises as the flow of condensate increases. When the bell has been forced up to a definite point, the water-discharge valve *D* opens, the steam supply is temporarily closed, and the water is forced out at *C*. When the water returns to its normal level, the bell moves to a lower position and opens up a steam valve.

267. Other Types.—The **tilting type** of steam trap, Fig. 94, is balanced by a counterweight. The water enters at one end when the trap and weight are in the positions indicated by the full

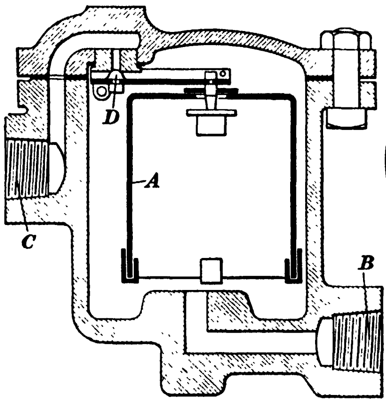


FIG. 93.

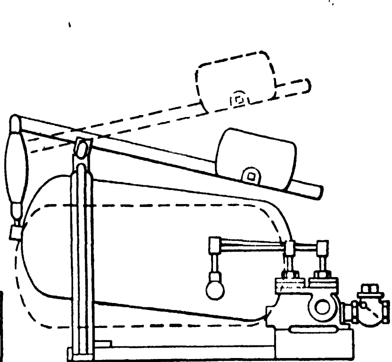


FIG. 94.

lines. The weight of the water gradually lowers the position of the trap to the position indicated by the dotted lines; this opens the valve and allows the steam to force the water out of the trap, the weight being raised as shown. The empty trap is then brought to its original position by the counterweight falling, and the operation is repeated.

The separator illustrated in Fig. 95 is in part a trap; yet it is essentially a medium for separating steam and hot water. This particular type of separator is sometimes used on a circulating, or 'blow-through,' system. When the steam and water are finally discharged from the condensing dryer section, they go to this separator. Sometimes a separator of this type is used between two sections of dryers. The condensate and wet steam enters through opening 1 and forms a water seal, allowing the overflow to

move toward the air and steam chamber. The steam and uncondensed gases pass out at opening 3 into the wet-end dryers. The final steam passes out at opening 5 to the first dryer, and all the condensate passes through to the hot well or hot-water system.

268. Condensate Pumps.—The removal of condensate from the dryer is effected largely by the difference in pressure between the dryer and the condensate-removal system. A majority of these systems are equipped with some type of *condensate pump*

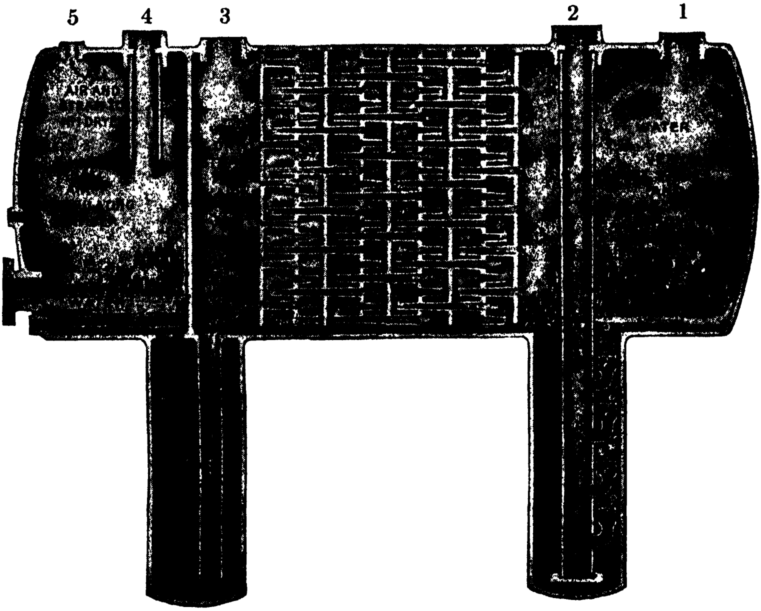


Fig. 95.

to create more suction on the siphon, in order to get complete removal of air and water from the dryer. A pump for this purpose must be so designed that it can take care of the hot water as well as some vapor and air. The well-designed centrifugal pump generally functions in a satisfactory manner if it is properly installed in the condensate-removal system. Another type of condensate pump that is often used is a two-cylinder horizontal reciprocating pump. This pump has a more positive action, but must be kept primed with cold water, in order that it may not get vapor- and air-bound. Centrifugal pumps must also be primed.

Many condensate-removal systems have a receiver just ahead of the pump, so that the condensed water will be pulled from the bottom of the receiver and thus enable the pump to operate more satisfactorily. In some cases the pumping unit consists of the receiver and pump, while other installations have a separate receiver tank in the line ahead of the pump.

The hot water is pumped by the condensate pump to a hot well or direct to the boiler house. It is essential that all the condensate water from the dryers, as well as from other parts of the mill, be utilized, so that the boiler house can operate on a minimum of raw water. The condensed steam from the dryers is the major source of the boiler make-up water; and it not only retains a temperature of 175° to 200°F. but it is also a pure water that does not require treatment in the boiler house. Therefore, it is doubly important that a condensate-removal system be so installed that it returns all possible hot water to the boiler house.

269. Summary of Paper-Drying Problems.—The cost of drying paper is one of the major items of expense in the operation of a paper mill. It has been pointed out that the first, and, perhaps, the most important, operation is to be certain that all water in the sheet that can be removed by mechanical means is taken out by the press section: this is obvious, since it costs twelve to fifteen times as much to remove water by evaporation on the dryers than to remove the same amount by mechanical means.

It is likewise important to have a satisfactory and efficient steam-supply system that will maintain the proper gradation of temperatures throughout the dryer section. The amount of exhaust steam from the prime mover and the percentage of live steam added to maintain proper drying conditions are factors affecting the type of drying system that may be selected for any particular paper machines. Perhaps one of the most important features is the piping layout, which must be properly designed and installed to get satisfactory drying conditions.

Many condensate-removal systems are on the market, and all have their good and bad points. In general, it can be said that a simple system is more satisfactory than a complicated one, since there should then be fewer parts to get out of order or to be renewed. The fundamental principle of all drying systems is to introduce only enough steam for effective drying and to remove

the condensed steam from the dryers as it accumulates: any good steam-supply and condensate-removal system should accomplish this.

DRYER FELTS

270. Types of Dryer Felts.—Various types and weights of dryer felts are sometimes required on machines making different grades of paper. The *function of the dryer felt* is to carry the sheet of paper, hold it against the face of the dryer, and allow the vapor to pass through it, to be carried off by the ventilating system. *Cotton dryer felts* with single, duplex, or triplex weave are commonly used. The *asbestos felt*, with about 60 per cent cotton and 40 per cent asbestos, is also extensively employed on various grades of paper.

The single-ply cotton dryer felt is made in various weights. The so-called 6/10 weighs 4.36 oz. per sq. ft. The so-called *duplex felt*, which might be called double woven, weighs approximately 5.6 oz. per sq. ft. The *triplex*, which is a so-called *triple weave*, weighs approximately 6 oz. per sq. ft. The asbestos felts also vary in weight to some extent: a standard type used on high-speed news machines weighs 6.4 oz. per sq. ft.

In addition to being porous and having a smooth surface, it is essential to use a felt that will not shrink or stretch too rapidly.

271. Importance of Controlling Felt Tension.—The control of the tension of the felts is a most important feature of the management of dryers. Efficient and uniform drying action of the dryer surfaces can be obtained only by securing a close and uniform contact between the paper and the dryers. A careful inspection of the felt tension throughout the nest will often indicate adverse conditions, either because the felt tightener is badly placed or because it does not have sufficient range and promptness of action as a felt loosener. A dryer felt, if made of cotton, will shrink rapidly when it is wet, and it will slacken promptly as it dries. If the tighteners are not so placed as to compensate for this shortening and lengthening of the felt, the life of the felt and the quantity and quality of the output will suffer.

272. Putting On a New Felt.—The procedure for removing the old felt and putting on a new one is essentially as follows: The

tighteners are first slackened, and then the old felt is cut across the machine. If there is no old felt on the machine, a rope must be threaded through the dryers, in the middle, following exactly the path of the felt around the dryers, felt rolls, tighteners, etc. The new felt, which comes in a roll, is then laid down across the machine, between the last dryer and the calenders. The end is cut square, and the new felt is then sewed to the end of the old felt. If there is no old felt, the end of the new felt is attached to the end of the rope, and the dryers are started up. If the lower felt is being replaced, the new felt goes down under the dryers into the basement or pit. When the last of the old felt comes out, the end of the new felt is detached from it, and is sewed to the other end of the new felt.

273. Dryer-Felt Seams.—The *seam* is conveniently made by tacking the ends, joined squarely, to a board, with about $1\frac{1}{2}$ to 2 inches extending. Following a thread, a straight line is drawn across the felt. A long raveling, or regular dryer-felt sewing thread, as long as can be handled without snarling, is threaded into a needle, and the two ends are sewed together on the mark. A good stitch is to put the needle down about $\frac{1}{4}$ inch from the edge, up about 2 inches along the line, down again through the first hole, up through a new hole 4 inches from the first, down again through the second hole, and so on. A quicker method is to pass up and down alternately, every 2 inches or so. For a nice job, the ends should be inside the felt, so as not to mark the paper; but they are often left outside, since it is then much easier to sew.

The **riveted dryer-felt seam** is used rather extensively on many paper machines because it is put in more rapidly and the tension can usually be made more uniform. The two ends of the dryer felt are overlapped 8 in. to 12 in., and a number of rows of small, split copper rivets are driven and clinched over on the side of the felt that does not come in contact with the paper. These rows are staggered in such a manner as to make a solid seam, but one that does not mark the paper. This type of seam is used to a large extent on coarse papers, and it might not be suited to a machine making fine papers. It is particularly suitable for the asbestos dryer felt, the seam of which tends to pull out more easily than on a cotton felt.

Various types of special seams have also been developed, but none are used extensively. The so-called *clipper type* has been tried out, and it is reasonably simple to put on. It is better adapted to narrow machines, since the seam has the appearance of a clipper-type belt fastening, with metallic loops on each end of the felt, which are brought together and fastened by a rawhide or metal stick being inserted inside the loops. The *glued seam* is successfully used on some machines and for certain types of dryer felts. The further development in the quality of adhesives may result in the more general use of the glued seam.

274. Strength of Felts.—Dryer felts, unlike press felts, are usually made of cotton instead of wool, and they are sometimes $\frac{1}{4}$ inch thick. They are much stronger than press felts, having a breaking strength of 300 pounds per inch of width; the breaking strength of the average press felt is about 60 to 70 pounds per inch of width.

275. Starting the Felts.—The great strength of a cotton dryer felt, in conjunction with its decided shrinkage when wet, causes tremendous strains on the dryer felts and rolls. In starting up a dryer part with a new felt or with an old felt, start the dryers free of paper and run slowly, with the felt stretchers slack at first, to see that all the rolls turn and that the felt does not catch anywhere.

Steam is put into the dryers for about 20 to 40 minutes before starting the paper. If a dryer is partly full of water, it will retard the drying process and increase the power required for driving the dryer section.

276. Felt Must Run Straight.—When putting on a dryer felt, it may tend to run to the front side or back side of the machine, notwithstanding that every precaution has been taken to keep the run of felt straight and to sew the seam square across. The machine tender should bear in mind the simple rule: *A dryer felt will run to the tight side when tightened at the side at which it leaves the dryer cylinder; and it will run to the slack side when tightened at the side that is going to the cylinder.* Note that this corresponds with Arts. **250** and **255**.

The seam should always be squared up on starting, and any tendency to run ahead on either side can be corrected by making the travel of that side longer. If this be not done, the felt will be

unevenly stretched, and it will give plenty of trouble before it has been in service very long.

When shrinking, a dryer felt can exert a pull of 30 pounds or more per inch of face of felt rolls, unless the stretch roll automatically compensates for the shrinkage. This puts a bending moment on a felt roll, which will cause it to sag in the middle until the felt becomes too loose at the middle and too tight at the edges. The result is that the paper is not held tightly against the dryers and remains wet in the middle. Cockling troubles also result from these conditions, because minute bubbles of steam make small blisters in the paper, and lack of pressure imparts a sort of puckering to the paper as it dries.

277. Flapping.—When following the course of the paper through the dryer nest, the operator will perceive a continuous flapping of the dryer felts at certain points. This **flapping** is almost invariably caused by inaccurate spacing of the dryer gears or by some imperfection of the drive. Many old machines have been speeded up in order to increase production, but excessive breaks of paper have occurred on the dryers, and the desired result is not attained. By watching a flapping felt and counting the flaps per revolution of a dryer, the relationship between the drive and the flap will be perceived.

Flapping of dryer felts may also be caused by an eccentric dryer, one that does not rotate about its axis, and it may likewise be caused by a warped dryer. To ascertain whether or not a dryer is eccentric or is warped, hold a stationary pointer close to the revolving dryer surface; if the revolving surface is always the same distance from the pointer, the dryer is turning true; but if not, it is eccentric or warped, and the degree of eccentricity can be readily noted.

A lack of symmetry of a drying cylinder, caused either by eccentricity of its bearings or by its not being a true cylinder, will produce a circumferentially imperfect movement about the axis of revolution, which causes a flapping movement of the paper as it passes from one dryer to another; this occurs if either or both of two successive dryers are imperfect. Flapping is sometimes due to a lack of proper balance between the speed of the paper, the diameter of the dryers, and the relative position of the dryers.

278. Dryer-Felt Wrinkles.—When a slack part of the felt is folded over as the tension is put on the felt, a dryer-felt wrinkle may result. In some cases the wrinkle is short; but, when a long wrinkle occurs, it is difficult to remove, and the utility of the felt is often destroyed. Sometimes these wrinkles run diagonally across the felt, and sometimes they are straight.

In general, wrinkles are the result of the following causes: (*a*) dryer-felt rolls out of alinement; (*b*) unequal or incorrect tension on the automatic stretch roll; (*c*) dryer-felt rolls that have become badly coated with foreign material; (*d*) unequal moisture content in the paper as it comes to the dryers, which will, in turn, cause uneven shrinkage in the felt; (*e*) worn or faulty dryer bearings, causing uneven stretch in the felt.

Occasionally, the difficulty may be caused by a defective felt; but this is very rare, since the felts are carefully made and tested by the manufacturer. Dryer-felt wrinkles are sometimes caused by an accident in operation, such as allowing the felt to run to one side of the machine, or to sewing a seam that is not true. If water accidently comes in contact with a dryer felt, it often causes a wrinkle, and it may easily cause the felt to run off the machine and spoil the felt.

The *diagonal wrinkle* is usually caused by an incorrect alinement of the stretch roll or by a crooked seam. The stretch roll can be corrected so as to make the dryer felt pull properly and keep the seam straight. If the seam is straight across the machine when in operation, it is a good indication that it is functioning properly. In some cases it is necessary to use 'leaders,' or strips of paper wound around a roll, in order to obtain the proper tension and pull of the felt. On some machines, it is possible to use a spread roll or worm roll (Art. 204) in order to remove a straight wrinkle if it is too long. However, the general practice is tighten up on the tension to work out the wrinkle as well as possible, and to run the felt as long as feasible. A felt that has developed a wrinkle may fail in a relatively short time, and the most logical method to follow when a new felt is installed is to make sure that all parts of the machine are mechanically correct, so the felt will function properly. If the seam be correctly put in, the difficulties and dangers due to wrinkles will be greatly minimized.

279. Bulges.—A **bulge** is a slack place in the felt, probably about 2 feet wide and 3 feet long; it is usually caused by that part

of the felt's being held during a jam in the dryer, or by allowing a thick, bulky wad of wet broke to run around the circumference of a dryer.

Bulges causing wrinkles are rare; yet it sometimes happens that, when taking a wad of paper from the bottom dryers, the wet paper becomes jammed between the dryer-felt roll and the upper dryer. Should the dryers be run a few feet and this condition be not noticed by the operator, the felt would go ahead on either side of the jam, while the felt under the paper would be held and stretched, even to the bursting point.

A bulge must be treated somewhat differently from the ordinary diagonal wrinkle. There will be two short diagonal wrinkles, each point of development being each outside edge of the beginning of the slack area. By placing a heavy leader around the roll just outside each point of development, the felt is driven still more forward at those points, thus reducing the tension by the gradual increase in width of the slack area; this action prevents the development of the slack into wrinkles.

280. Shrinkage.—Paper shrinks a considerable (but varying) amount in width as it passes from the wet end of the machine to the reel. The table on page 198 gives some shrinkage per cents as found by actual measurement. Certain details of manufacture are also given, from which the student can get some idea of what to expect. The heavier the paper and the slower the stock the greater the shrinkage; the more groundwood the less shrinkage; the more rag the more shrinkage. A lengthwise stretch of 7 per cent has been noted between couch and calenders. Tight draws increase shrinkage and stretch.

281. The Spear and Its Use.—When paper breaks and winds around a dryer, it must be cut off with a spear. The **spear** is a long, light pole, with a sharp steel head that is sometimes slightly curved. It is jabbed under the edge of the paper, as low as possible on the upcoming side of the dryer, and is pushed as far as possible; but it is withdrawn when the cut is at the highest point, as the dryer turns. A new jab is made as the cut again comes up, until the paper is cut clear across. It is a good plan to run the cut part over to the next dryer and along the lower tier.

282. Use of Compressed Air.—On the modern paper machine, compressed air is of more importance in keeping the dryers clear of broke than is the spear or other implement used around the machine. Many of these machines have enclosed dryer gears, so that it is possible to blow the broke or pieces of paper through the machine to the back side. The compressed-air outlets are

SHRINKAGE IN PAPER AND BOARDS

Grade	Basis weight 24 by 36	Composition, per cent					Shrinkage, per cent
		Rag	Sulphite	Groundwood	Kraft	Waste paper	
Kraft bag	30	...	...	..	100	..	5.58
Kraft wrapping	50	...	...	..	100	..	4.70
Gray fiber	50	...	15	25	60	..	2.90
Filled wood board (pulp liner with waste-paper filler)				caliper, 0.020 to 0.040			3.99
Chipboard (single pulp lined)				caliper, 0.030 to 0.040			3.41
Chipboard				caliper, 0.015 to 0.020			4.54
Chipboard				caliper, 0.025 to 0.035			3.99
Chipboard				caliper, 0.040 to 0.055			3.41
Testboard, brown lined, 80 pounds				caliper, 0.016			5.12
Testboard, brown lined, 60 pounds				caliper, 0.019			4.54
	Basis weight 24 by 36	Rag	Sulphite	Groundwood	Kraft	Waste paper	
No. 1 book	..	...	40	..	60	..	4.00
No. 1 envelope	..	...	87½	..	12½	..	2.46
Book	..	...	30	20	...	50	2.05
News	32	...	25	75	...	..	2.49
Bond	..	20	80	..	...	..	5.38
Stationery	..	15	85	..	...	..	5.66
Writing	..	...	45	10	...	45	2.42
	Basis weight 17 by 22			Condition of stock			
	24	85	15	Medium			4.60
	20	60	40	Medium			5.27
	28	40	60	Medium			6.85
	20	60	40	Medium			4.23
	20	60	40	Medium			5.70
	28	100	...	Slow			5.56
Writing	20	80	20	Slow			7.65
	16	80	20	Slow			6.90
	37	10	90	Free			4.14
	20	40	60	Medium			8.40
	32	45	55	Free			5.34
	24	20	80	Medium			4.05
	24	20	80	Medium			7.30
Bristol	..	...	...	Free			6.35
Blanks	..	...	...	Free			5.20
Cartridge	..	...	...	Free			5.30
Tariff	..	...	...	Medium			5.30
Featherweight	..	...	...	Free			2.30
Offset	..	...	...	Free			4.70
Litho	..	...	...	Slow			4.00

located along the front side of the machine and are generally equipped with long hoses and pipe jets, which enable the machine crew to reach almost any part of the dryers, even on the wide paper machines. The high-pressure compressed air is capable of removing the paper that is wound around the dryer in case of a bad break on the paper machine. Sometimes fairly large slabs of paper are taken down the dryers with the assistance of compressed-air jets. The use of compressed air makes it seldom necessary to shut down, or slow down, the paper machine, since the dryers can be quickly cleared. About the only time that it is necessary to stop the dryers is when a bad plug gets underneath one of the doctors: hooks and spears must then be used to remove the plug, which is blown across to the back side, and the dryer is cleared.

PAPER-MACHINE VENTILATION

283. The Drying Problem.—As the sheet enters the dryers, it usually has a content of 28 to 35 per cent bone-dry fiber. This means that it is necessary to evaporate approximately two tons of water for every ton of finished paper produced, since the moisture in the finished sheet varies between 5 and 10 per cent (see Art. **286**).

As the sheet enters the dryer section, it is usually at or a little less than the room temperature, which averages in most mills 60° to 70°F. As the paper travels through the dryer section, it gradually heats up to, say, 180° to 190°F. On some particular grades of paper, this latter temperature is kept as low as possible; but it is inadvisable to attempt to dry at any higher temperatures on ordinary grades of Fourdrinier papers, because of the danger of over-drying the sheet, which makes it brittle.

Various systems have been devised to produce a gradual increase of temperature through the dryer section, from the wet end to the dry end; but the normal removal of water from the sheet maintains a reasonable temperature gradient if the steam-supply and water-removal system is functioning properly, and if the vapor removed from the sheet is adequately carried away by the ventilating system.

284. Principles of Ventilation.—The moisture taken out of the sheet by the dryers must be removed from the machine room, and

an adequate amount of warm fresh air must be supplied to replace the moisture-laden air that was removed. Some of the older and slower-running machines are not equipped with *hoods*, but for the modern and high-speed machines the hood is not only an economical part of the equipment but also almost a necessity, in order to obtain satisfactory drying conditions. The hood makes it possible to concentrate the vapor-laden air above the machine, and to exhaust it from the hood so that it carries the highest amount of moisture possible. If the ventilating fans that are connected to the exhaust ducts from the hood are inadequate, it will result in slow drying. On the other hand, if the volume of air and vapor removed is in excess of the amount actually required, there is a definite loss caused by the excess heat that is removed. This is an important problem, particularly in the northern mills during the cold season.

The warm air supplied to the paper machine is usually discharged into the basement or pit, so it will do its full work in water removal. The water-carrying capacity of air is discussed fully in Section 9 of Vol. IV, under *Heating and Ventilation*, where a psychrometric chart and a table are given, by means of which the amount of water that can be carried away by a cubic foot of air at different temperatures may be found.

285. Factors That Influence Drying.—Briefly, the problem of evaporating moisture in the sheet by the dryers is influenced more or less by certain physical conditions. There must be sufficient dryers to remove the moisture from the sheet at the speed of machine operation, and sufficient opportunity for the vaporized moisture to be carried off. If the dryer rolls are fairly far apart and there is a long draw, the opportunity for air circulation and vapor absorption is much better than on machines having a short draw. However, there is a limit to the length of draw between dryers, because if the draw is too great there is danger of excessive movement and flapping of the paper, and the sheet may break in the dryers. As previously mentioned, the air supply must be sufficient but not excessive. A porous dryer felt assists in speeding up the removal of water from the traveling sheet of paper. As a felt gets older and more compact, the vapor is not removed so rapidly, and the amount of steam required for drying increases proportionately. The use of hoods, blower

systems, felt dryers, and vapor economizers are also factors in the drying problem: these will be considered later.

286. Amount of Water Evaporated by the Dryers.—The amount of water that is evaporated by the dryers is readily calculated by the following formula:

$$w = \frac{p - d}{d}$$

In which w = pounds of water evaporated by dryers per pound of finished paper;
p = per cent of bone-dry paper in finished sheet;
d = per cent of bone-dry paper in paper entering dryers.

Example.—A newsprint paper machine has a production of 100 tons of paper per day. The paper enters the dryers 30% b.d. and leaves 92% b.d. Calculate (*a*) the pounds of water evaporated per pound of finished paper; (*b*) the pounds of water evaporated in 24 hours.

Solution.—(*a*) Substituting the values of p and d in the formula.

$$w = \frac{92 - 30}{30} = 2.07 \text{ lb. of water per pound of paper made}$$

(*b*) Production in 24 hr. = 100 × 2000 = 200,000 lb., and 200000 × 2.07 = 414,000 lb. = 207 tons of water evaporated in 24 hours.

The chart given herewith provides a quick method for determining the number of pounds of water evaporated per pound of finished paper. As applied to the foregoing example, lay a straightedge so it passes through points 30 and 92 on the right-

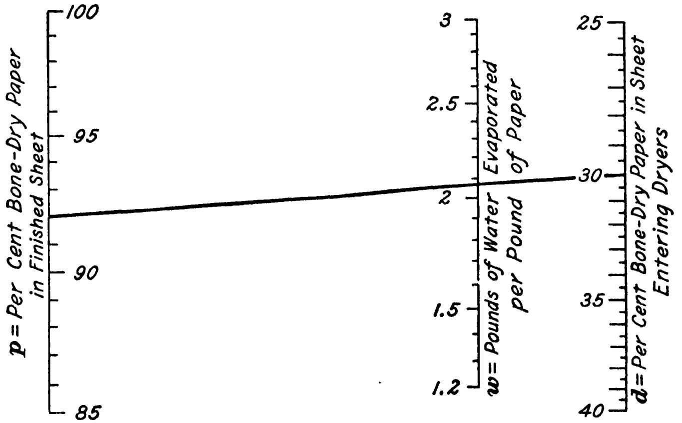


Chart I

and left-hand scales respectively, and note that it crosses the middle scale at point 2.07.

287. Number of Dryers Required.—A rough approximation to the capacity of the dryer part may be derived as follows: If the paper being made is newsprint or its equivalent in furnish and weight, one 48-inch dryer should be allowed for every 20 ft. per min. of paper speed; for a 60-inch dryer, allow one dryer for every 25 ft. per min. of paper speed. Consequently, if the paper speed is 1000 ft. per min., there should be 1000 ÷ 20 = 50 48-inch dryers, or 1000 ÷ 25 = 40 60-inch dryers. For book and writing papers, allow one 48-inch dryer for every 10 ft. per min. of paper speed.

It is well recognized that the per cent of moisture of the sheet entering the dryers, the type of hood and ventilating system, as well as other operating factors, will affect the drying requirements and the capacity of the dryer part.

The following table represents actual practice; it checks rather closely the rough rule just given:

Book and Writing Paper Machines

Maximum speed of paper, feet per minute	No. of dryers. Diameter, inches		
	48	60	72
250	24	20	17
325	30	26	22
400	36	32	27
450	42	36	30
500	48	40	37
Kraft and Newspaper Machines			
300	15	12	10
375	18	15	13
450	22	18	15
525	26	21	18
600	30	24	20
1100	..	42	40
1300	..	50	..

288. Calculating Dryer Surface Required.—The following empirical formula may be used for calculating the amount of

dryer surface required for various kinds of papers. In this formula,

S = speed of paper in feet per minute;

L = peripheral length (in feet) of dryers in contact with paper when in operation;

t = temperature of steam at pressure carried, in degrees Fahrenheit;

d = thickness of dryer shell in inches;

w = weight of paper per ream of 500 sheets, 24 × 36 inches.

Then,

$$S = \frac{2.7L(t - 212)}{wd} \qquad (1)$$

and

$$L = \frac{Swd}{2.7(t - 212)} \qquad (2)$$

EXAMPLE 1.—Suppose it is desired to make 30-pound newsprint at a rate of 1000 ft. per min.; how many dryers having a thickness of ¾ in. are required when the steam pressure is 10 lb. per sq. in., gauge?

SOLUTION.—Referring to the steam table at the end of Vol. III, the temperature of the steam at 10 lb., gauge, is 239.4°. Neglecting the fraction, the value of t is 239. Substituting in formula (2) the values given,

$$L = \frac{1000 \times 30 \times 0.75}{2.7(239 - 212)} = 309 \text{ ft.}$$

The value of L just found is the length of the periphery of dryer shell in contact with the paper. But, since a little less than one-half of the periphery of any dryer is in contact with the paper, the periphery of a single dryer must be greater than 309 × 2 = 618 ft., which is far too great for any dryer. The periphery of a 48-inch cylinder is $\frac{48 \times 3.1416}{12}$ = 12.5664 ft., and one-half of this is 6.2832 ft. Assuming that the length of the arc of contact between the paper and the dryer is 6 ft., the number of 48-in. dryers required is 309 ÷ 6 = 52. *Ans.*

EXAMPLE 2.—How many feet of peripheral contact on dryers is required for 18-lb. tissue at 150 ft. per min., the thickness of the dryer shell being 1½ in., and the steam pressure 75 lb. per sq. in., gauge? How many 60-inch dryers would be required?

SOLUTION.—Referring to the steam table at the end of Vol. III, the temperature of the steam is 321° very nearly. Substituting in formula (2) the values given, the total length of the peripheral contact is

$$L = \frac{150 \times 18 \times 1.5}{2.7(321 - 212)} = 13.76 \text{ ft.} \quad \textit{Ans.}$$

In example 1, it was found that the arc of contact for a 48-in. dryer might be taken as 6 ft.; for a 60-in. dryer, it may therefore be taken as $6 \times \frac{60}{48} = 7.5$ ft. Consequently, the number of 60-in. dryers is $13.76 \div 7.5 = 1.83+$, or 2 dryers. *Ans.*

289. Calculating the Air Supply.—The water evaporated by the dryers is carried away by air, which is supplied and taken away by some mechanical means. A given quantity of air, say a cubic foot, will absorb a certain amount of moisture (water); and if the air be dry and warm, it will absorb much more moisture than cold, damp air will absorb.

Under average conditions, a cubic foot of air will carry about 14 grains of water, which is equivalent to $7000 \div 14 = 500$ cu. ft. of air per pound of water. Referring to Art. **286**, a 100-ton newsprint machine would evaporate 207 tons, or 414,000 lb., of water per day of 24 hours. This is equivalent to $414000 \div 24 \times 60 = 287$ lb. per min. At this rate the machine will require $287 \times 500 = 143{,}500$ cu. ft. of air per minute. An additional 5 per cent should be added to take care of the dried paper that goes to the broke beater, and another 10 to 15 per cent to provide for moisture picked up at the wet end of the machine, and for other contingencies.

Since each mill and paper machine presents a distinct ventilating and drying problem, it is essential to take all factors into consideration. Ventilating problems should be fully analyzed by competent engineers that specialize in this kind of work.

290. Air Supply.—The air is usually supplied by a fan located in the basement or adjacent to the back side of the machine. The outside or cold air is brought through a nest of steam pipes and forced through ventilating ducts at points where the air is needed. If there is sufficient room in the basement, a series of ducts are generally located at right angles to the return dryer felt. The heated air supplied by these ducts removes the excess moisture in the dryer felt and makes the felt more uniformly dry across the machine when it contacts the wet sheet of paper being dried. The warmed air then becomes moisture laden, and goes through the machines and out the exhaust duct.

The modern mill usually has hoods on each machine and ducts that supply warm air to other parts of the machine room, particu-

larly near the roof, to prevent an accumulation of moisture and condensate. Some machine rooms are equipped with unit heaters, to provide warm air locally.

291. Vapor Economizer.—Since the cost of drying paper is one of the major items of expense, particularly in newsprint and kraft mills, the reclamation of heat in the vapor removed from the machine is an important problem. This is particularly true of the mills in the northern climates, and the use of the **vapor economizer,** Fig. 96, is quite essential and is standard

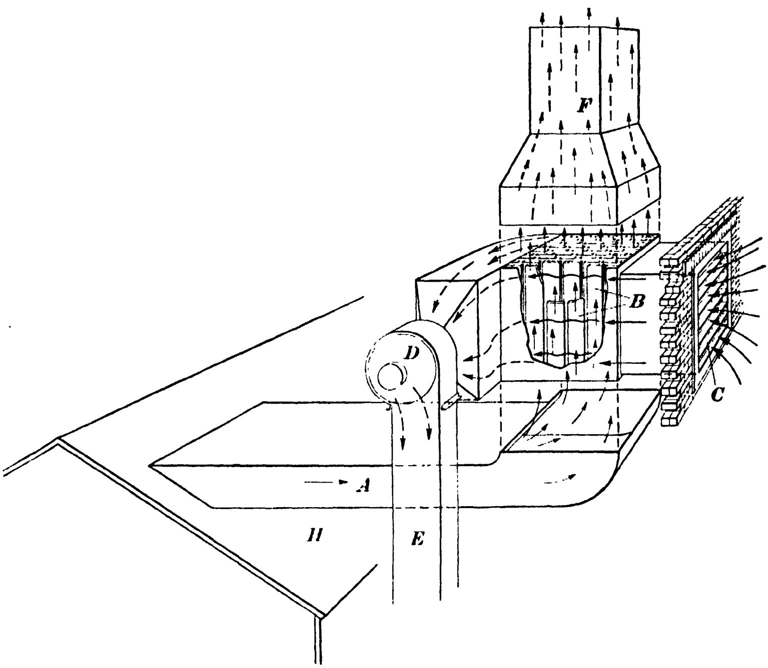


FIG. 96.

practice. This type of economizer is also used to advantage in warmer climates to keep more uniform humidity conditions in the hood and the machine room. This economizer is generally constructed of galvanized pure iron or copper plate, and the vapor that is being removed comes from the hood *H* through vent *A* into the heat exchanger and contacts the tubes *B*, through which the cold outside air is being drawn from the louvres *C*. The out-going high-temperature humid air transfers much of its

heat to the in-coming fresh air, which is then supplied, through fan *D* and ducts *E*, to the paper machine or paper mill as needed. The vapor leaves the machine room through exhaust ducts *F*. The subject is more fully treated under *Heating and Ventilation*, Section 9, Vol. IV.

292. High-Pressure Air-Supply System.—A special patented system is used on many machines to even up the drying across the sheet, to increase the drying capacity of the dryer section, and to decrease the steam consumption per ton of finished paper. This system consists of a set of warm-air ducts, so located between the dryers that a current of high-pressure air is forced between the dryers: the outlets are placed on the front and back sides of the machine at alternate dryers. The high-pressure current of warm air breaks up the vapor pockets that sometimes develop near the center of the dryer. The positive movement of the air at this point assists in carrying off the vapor and speeds up the drying. The air-supply system, the duct work, and the outlets must be designed to suit the particular conditions of the machine using them. In general, better results are obtained on the wide paper machines, since there is then less opportunity for the vapor to be removed by natural draft or normal movement of the vapors.

293. Humidity.—There are three principal factors concerned in the removal of the water evaporated by the dryers: (*a*) the volume of air passing through the dryer part relative to the amount of water to be evaporated; (*b*) the temperature of the air; (*c*) the humidity of the air. A cubic foot of dry air at any particular temperature will hold a certain definite amount of water, the exact amount depending on the temperature of the air. When the air has taken up all the water it can hold, it is said to be **saturated.** If saturated air be cooled, it will deposit some of its moisture in the form of dew or rain; but if it be heated, it can then absorb more moisture. Saturated air is also said to have a **relative humidity** of 100 per cent; and air containing less moisture than that required to saturate it will have a relative humidity ranging from 0 per cent, when it is perfectly dry and moisture free, to 100 per cent, when it is saturated. The less saturated it is the more moisture it can absorb and the more it can be cooled before reaching the **dew point,** which is the temperature at which

precipitation or condensation occurs, *i.e.*, the temperature at which the relative humidity is 100 per cent. The student is advised to re-read Arts. **129** and **130** of *Elements of Physics*, Vol. I, and to refer to the use of the *psychrometric chart* in Vol. IV, Sec. 9, under *Heating and Ventilation.*

294. Removing the Air.—Referring to Fig. 79, the illustration shows a design of a hood *H* over a dryer nest, with one or more stack openings *V* on top. Each stack is provided at its outlet with a fan for drawing the moisture-laden air from the hood and discharging it out of doors. In some mills, a tall stack, with natural draft, is preferred to the fan. Since this arrangement of dryer hood, fans, and stacks will tend to draw the air from the machine room more easily than from the inside of the dryer nest and from under the dryer felts, and since the air from the back side is generally more moisture laden than on the front side, the hood usually overhangs more on the driving side, so as to induce the air to come from under the felt and into the hood. If moist air be not removed before it cools, the moisture is condensed and drips, or sweats, when the air strikes a cold surface. In some cases when fans are in use, the stacks may discharge through openings in the walls instead of through roofs.

295. Roofs.—The roof of the paper-machine room should be of an anti-sweat design; it should be constructed of treated wood, gypsum block or slabs, or concrete, with a liberal thickness of insulating material over the concrete.

The accumulation of moist air under a wooden roof induces decay. Untreated timbers seldom remain in good condition for more than seven years. It is important to have a ventilating system that removes the moisture-laden air, to prevent it from collecting on the under surface of the roof and causing decay. The roof should also be well insulated, especially in the colder climates, so that the temperature of the inside of the roof is not lowered to a point that causes it to sweat, or the condensate to gather and drip on the machine parts or the floor.

296. Size Press.—On paper machines that produce high-grade writing papers or other grades that require exceptional sizing that cannot be applied in a beater, a **sizing press** is installed at some part in the dryer part. There are various methods of surface sizing, but usually the paper is partially dried, run

through the size press, and then further dried out. The sizing is sometimes applied by a series of rollers that permit a certain amount of sizing material to be applied to both sides of the sheet: some grades of paper are submerged in the size solution before passing through the size press.

The drying of sized paper is described in the Section on *Sizing* in Vol. IV. A festoon dryer is shown in the Section on *Coated Papers* in this volume.

297. Dryer-Section Variables.—The following are some of the papermaking variables appertaining to the dryer section of the paper machine:

1. Type and regulation of dryer drive.
2. Diameter of dryers.
3. Temperature and temperature gradient of dryer section.
4. Design of steam-supply system.
5. Type of dryer drainage system.
6. Type of ventilating system for dryers.
7. Design of dryer rolls and their bearings.
8. Number of dryers.
9. Position of dryers and length of draw between dryers.
10. Number of dryer-felt rolls.
11. Type of material used in dryer felt.
12. Weave, weight, and porosity of dryer felt.
13. Width of dryers and of dryer felt.
14. Amount of tension on dryer felt.
15. Type of dryer-felt guide.
16. Number, diameter, and temperature of felt-dryer rolls.
17. Location of felt-dryer rolls.
18. Magnitude of draw between the several dryer sections.
19. Amount of draw between spring roll and calender stack.

In addition to the above, there are other minor variables in connection with the problems of steam supply, water removal, and ventilation which have been mentioned heretofore.

PAPERMAKING MACHINES

(PART 3)

EXAMINATION QUESTIONS

1. (*a*) What is meant by the dryer section? (*b*) If the consistency of the stock is $\frac{1}{2}\%$ and the paper enters the dryers $33\frac{1}{3}\%$ b.d. and leaves them 92% b.d., what proportion of the total water removed from the paper takes place here?

2. (*a*) Explain the function of the smoothing rolls. (*b*) Where are they located and why?

3. (*a*) Why is a felt used on dryers? (*b*) Of what is it made? (*c*) Describe the asbestos felt and state its advantages.

4. Does a dryer felt stretch or shrink when wet?

5. Explain the contrivance by which any change in the length of a felt is taken care of automatically.

6. Why should air and why should water be removed from dryers?

7. Explain the presence of water in the dryer.

8. Describe two methods for removing water.

9. Suppose 1 lb. of steam is put into one dryer at 10 lb. gauge pressure and removed as steam as 0 lb. gauge, and 1 lb. into a second dryer at 0 lb. and removed as water at the same temperature; which will dry more paper?

10. (*a*) What is the principle of the guiding of felts? (*b*) Explain how they may be guided by the stretch roll.

11. (*a*) What is the function of the steam joint? (*b*) What precautions should be taken with it?

12. What means may be used to maintain a uniform temperature in the dryers?

13. What is a steam trap for, and how does it work?

14. Explain how a new dryer felt is put on.

15. Mention some causes of flapping of the paper on the machine.

16. What factors influence the rate of drying of paper?

17. If a machine were to make 55 tons of paper containing 8% moisture in 24 hours and the paper contained 31% bone-dry paper on entering the dryers, how much water would be removed (*a*) in drying? (*b*) per pound of finished paper?

Ans. $\begin{cases} (a)\ 108.2\ T. \\ (b)\ 1.968\ \text{lb.} \end{cases}$

18. What is meant by: (*a*) dew point? (*b*) relative humidity? (*c*) siphon? (*d*) felt dryer?

SECTION 1

PAPERMAKING MACHINES

(PART 4)

CALENDERS, SLITTERS, AND WINDERS

THE CALENDER END

DESCRIPTION OF CALENDERS

298. The Spring Roll.—At the calender end of the dryer part, the paper passes under a spring roll *N*, Fig. 78, before entering the nip of the calender. This is a paper roll, which is supported in spring bearings, one of which is shown in detail in Fig. 97. Referring to Fig. 97, the bearing proper *B* is a floating or moving

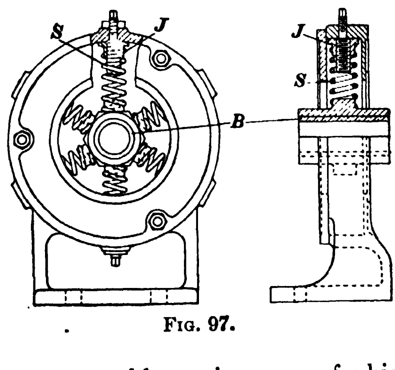


FIG. 97.

bearing, entirely supported by springs, one of which *S* is shown in detail: it is kept in position and adjustment by the bolt *J*. When the paper tension varies, as the paper is pulled from the dryers by the calenders, this spring roll can rise or fall in its bearing because of the actions of the springs, and this compensates for temporary variations of the tension.

299. The Calender Stack.—A 9-roll stack of calenders is shown in Fig. 98. The paper, as it is passed from the dryers, is

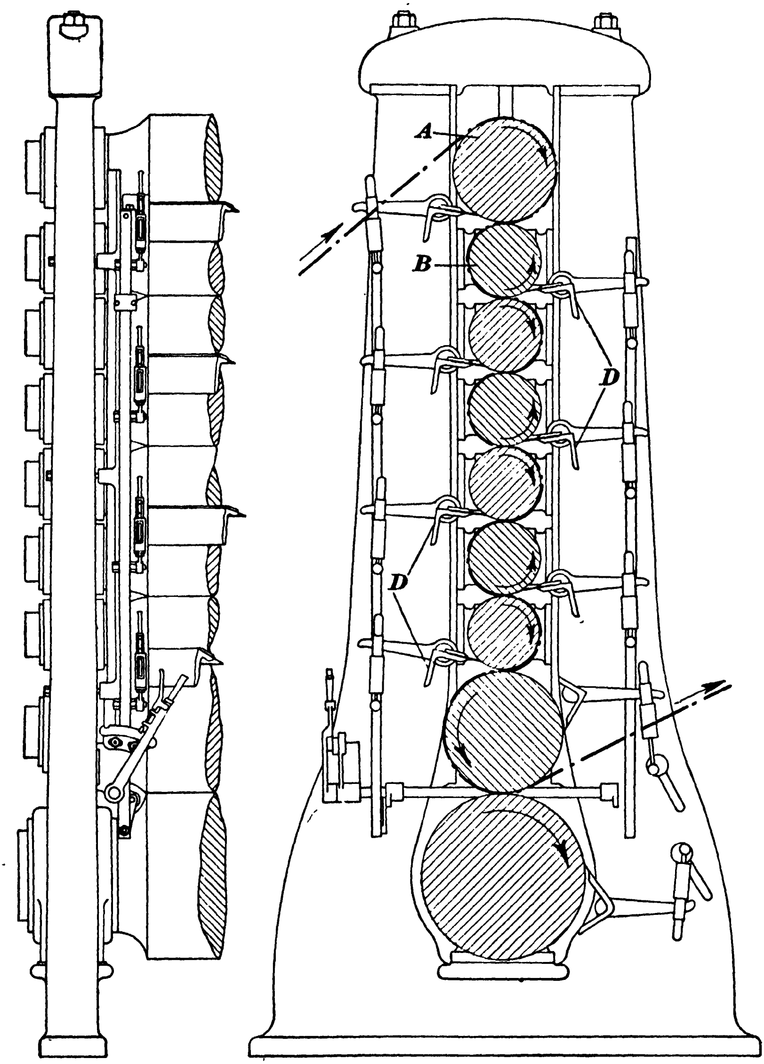


FIG. 98.

brought over the top roll and enters between the top roll *A*, Fig. 98, and the roll *B*, next below it. The paper is guided by bent steel fingers, or ductors, into each succeeding nip. On

coming out from the first nip, the paper is guided back into the next lower nip, proceeding thus from nip to nip until it finally comes out on top of the bottom roll, on the side away from the dryers and toward the reel. An 8-roll stack is more commonly used, and the paper is passed directly into the nip between the top roll and the adjacent lower roll. This method of putting the sheet through the calender is more practical, and is essential on the modern high-speed paper machine.

The steel doctor blades D scrape off the paper as it comes from each nip, and thus keep it from traveling up the rolls. The doctors are always on the outrunning side of the rolls. The *ductors* lead the paper to the nips; the *doctors* lead the paper away from the rolls.

A popular type of calender doctor has a universal control, by means of which, all the doctors are connected together, and all are thrown against or away from the rolls; but individual doctors can be operated independently, if necessary. Each doctor has a flexible blade of soft metal, so the chilled-iron calender rolls will not be injured by contact with it; and the doctors are all held against the rolls with a uniform, relatively light, pressure by springs, the tension of which is adjustable.

The back tender throws the end of the paper into the entering nip, and it automatically feeds through the calenders until it is scraped off the reel side of the bottom roll; it is then carried by the back tender and wrapped around a reel cylinder. On machines that are not equipped with doctors and ductors, the calender stack is a prolific source of accidents, because of the tendency to use the fingers to feed the paper through the nips. The safe way is to draw the loose end down tight with one hand, and then push the sheet into the nip with the closed fist of the other hand. A good machine man is **always careful everywhere.**

Fast-running machines are frequently equipped with an arrangement for blowing a lead strip by compressed air from the last dryer to the calenders.

300. Purpose of the Calenders.—The purpose of the calender stack is to compact the paper and give it a fine, smooth finish. This effect is achieved on both sides of the paper by the friction and pressure of the rolls between which the paper passes. The lowest roll of the stack is driven mechanically, and this, in turn,

drives those above it by friction. There is a certain amount of slip between these rolls, and the result is that an enormous aggregate of friction acts on the paper as it passes through.

In order to give a fine finish, the calender rolls are made of a fine-grained cast iron that takes a high polish, and the surface is made of chilled iron. Since a soft paper is more easily smoothed than a hard paper, the surface of the paper is sometimes dampened (as for water finish) with a fine water spray or a steam jet, or calender water boxes, which contact the surface as the paper enters the calenders. If the paper is made too wet, the friction of the calenders may develop black spots on the sheet.

301. Use of Sweat Roll and Smoothing Roll.—Sometimes the paper is moistened on the surfaces by passing over a **sweat roll.** This is a small roll, like a dryer, but filled with cold water to condense moisture from the air on the paper, which will soften the paper and assist the work of the calenders. Moistening the paper with the intention of obtaining a fine glaze finish is a procedure also carried on in the finishing room on the supercalenders.

The use of smoothing rolls before the dryer nest, as shown in Fig. 78, smooths the surface of the paper while it is still very moist, and is therefore soft and pliable; they squeeze down the surface to a finish with much less pressure than the calenders must exert to get the same result, and should leave more strength in the paper, with no ill effect on the sizing.

302. Moisture in Paper at Calenders.—The paper should go to the calenders containing between 6 and 10 per cent of water, depending on the grade of paper being made. A sheet with a small per cent of moisture will not give a high finish; therefore, if the requirements of any particular grade of paper call for a high, smooth finish, it is advisable to carry as much moisture as possible going into the calenders. As previously stated, the presence of too much moisture in the paper going to the calender stack will result in blackening or mottling the sheet, so the moisture content must be carefully watched and controlled.

303. Calender Doctors.—Calender doctors must be capable of quick adjustment to the surface of the rolls, and they must be capable of exerting a fair pressure on the rolls; also, the blades

must be flexible enough to shape themselves to conform to the surface of the roll by means of the adjusting screws.

CALENDER TROUBLES

304. Hard and Soft Spots.—As the paper is passed over the reel and is wound into rolls, any inequalities in bulk will show quickly. **Bulk** is a term that expresses the thickness of paper as compared with its weight: a paper that is thick for its weight is said to *bulk well.* If a paper bulks unevenly across the machine, it will wind unevenly on the reel, making **hard** and **soft spots** in the roll. The hard places have the highest bulked paper, because the thickness of the paper makes it reel tighter than the paper that has a poorer bulk. A variation of this causes soft-feeling loose places in the roll. The back tender may correct the inequalities of bulking, causing soft spots in the roll, by trying to remedy the faults at the calenders. This can be done by altering the diameter of the calender rolls by changing their temperature. The place where the roll is hard indicates the part of the calender roll that should be heated by friction to increase the diameter at a particular point, so that the pressure will be greater where the hard spot occurs. Opposite the soft places on the reel, which show that the paper is thinner there, cold air is blown by air pipes from a blower onto the calender. This tends to reduce the diameter of the rolls at these points, which reduces the relative pressure at the same points, the result being that the paper is not calendered so severely where the soft spots indicate lack of bulk.

305. Correcting for Uneven Bulking.—In order to maintain the test strength of the paper, it is better to correct first for uneven bulking through the machine. The slices are the first sources of trouble: they should be of uniform height from the wire clear across the machine. The drier the paper is as it leaves the press rolls the better it will bulk. The press rolls should carry a uniform pressure and have accurate crowning, to correct bulking troubles. An even drying across the machine is essential. Felts that are damp in the center indicate uneven drying.

Every paper machine has its own characteristic troubles and faults, and every part of the machine should be examined thoroughly when there is trouble in making a good reel. The

trouble may be incorrect grinding of the press or calender rolls.

306. Causes of Some Calender Troubles.—The following are some causes of troubles at the calenders: Too little crown on the press rolls will cause soft spots on the edges of the reel rolls, while too much crown will cause soft spots in the middle of the reel rolls; in either case, all the press rolls should be calipered with micrometer calipers, and the faulty roll should be re-ground when the machine is shut down. The temporary remedy in either case is to hang more weights on the press-roll levers on the side where the paper is too thick, or to reduce the weight on the side where it is too thin. The trouble may originate at the slices, one side of which may be too high. If the variation in thickness is due to variation at the center, the trouble may be caused by a sag at the center of the slice, or to incorrect crowning of a press roll. The last opportunity to change the relative thickness of the two edges of the paper is at the calenders.

307. Causes of Breaks.—If the paper breaks between the calender rolls, the paper between the press sections should be examined. It may be too tight, especially between the couch roll and the first press, and between the first and second presses, where the paper is weak and easily overstrained. If the paper is not too tight between the presses, the trouble may be caused by the wire; some of the meshes may be filled up with dirt, which keeps the suction boxes from pulling at these points, and weak spots occur in the paper.

Sometimes the wire seam is raised: to correct this, tighten up the wire temporarily by means of the stretch roll. The wet felts should be examined for dried stock or hard spots: these can sometimes be located by examining the paper for small dark marks and spots, as it passes from the press to the dryers. These spots can often be removed by the careful use of a wire brush.

Breaking at the calenders can be caused by having the draws so slack that the edges crease at the nip of the press rolls and cause a calender cut.

Breaks at the calenders are often the result of having the paper too slack between the dryers. The tight dryer felts will then crease the paper at the edges, and it will break at the calenders.

308. Crown on Calender Rolls.—The maintenance of a smooth surface on the rolls is of major importance, particularly where the machine produces printing papers of various grades that demand good printing-surface characteristics. The thickness of the sheet is also of great importance in connection with the modern printing press; hence the crown of individual calender rolls, as well as of the entire stack, is of major importance. The reason for crowning the calender rolls is to compensate for the deflection of the bottom, intermediate, and other rolls caused by the weight of the rolls on top of them.

The calender rolls are usually cast solid and have a chilled surface. There will be a normal deflection of the bottom calender roll due to its own weight, which will vary according to the face (length) of the roll. For example, the bottom calender roll of a standard three-roll newsprint machine has a face of about 230 in., weighs approximately 35 tons, and must be crowned about 0.045 in. A prominent manufacturer of calender rolls gives the following figures regarding the crowning of his rolls:

102-inch face:

For a ten-roll stack consisting of 1 16-in. top roll, 7 10-in. intermediate, 1 14-in. next to bottom, and 1 20-in. bottom, 0.009 in. crown on bottom, 0.001 in. on top roll.

For a nine-roll stack consisting of 1 16-in. top roll, 6 12-in. intermediate, 1 16-in. next to bottom, and 1 22-in. bottom, 0.012 in. crown on bottom, 0.001 in. on top roll.

For a seven-roll stack consisting of 1 16-in. top roll, 4 12-in. intermediate, 1 16-in. next to bottom, and 1 22-in. bottom, 0.010 in. crown on bottom, 0.001 in. on top roll.

130-inch face:

For a ten-roll stack consisting of 1 16-in. top roll, 7 12-in. intermediate, 1 16-in. next to bottom, and 1 24-inch bottom, 0.013 in. crown on bottom roll.

For an eight-roll stack consisting of 1 16-in. top roll, 5 11-in. intermediate, 1 14-in. next to bottom, and 1 24-in. bottom, 0.011 in. crown on bottom roll.

162-inch face:

For a nine-roll stack consisting of 1 18-in. top roll, 6 13-in. intermediate, 1 18-in. next to bottom, and 1 28-in. bottom, 0.019 in. crown on bottom roll, with from 0.001 to 0.0015 in. on top roll.

For a seven-roll stack consisting of 1 18-in. top roll, 4 13-in. intermediate, 1 18-in. next to bottom, and 1 28-in. bottom, 0.018 in. crown on bottom roll.

228-inch face:

For an eight-roll stack consisting of 1 16-in. top roll, 5 16-in. intermediate, 1 20-in. next to bottom, and 1 32-in. bottom, 0.043 in. crown on bottom, 0.002 in. on next to bottom and on top rolls.

238-inch face:

For an eight-roll stack consisting of 1 18-in. top roll, 5 18-in. intermediate, 1 20-in. next to bottom, and 1 32-in. bottom, 0.049 in. crown on bottom, and 0.002 in. on next to bottom and on top rolls.

It is always well to put 0.002 or 0.003 in. crown on the next to bottom roll on the very wide stacks, and about 0.001 in. to 0.0015 on stacks of 170-in. face or less.

It is very necessary to have an adequate and accurate *roll-grinding machine*, and to have it properly installed on a foundation by itself, in order that calender rolls may be ground and crowned to the exact dimensions required. Measurements must be carefully made during the grinding of the rolls, to make certain they have the correct crown from end to end and that the curvature of the crown is correct. A special measuring device is available that enables the operator to keep an accurate check on the crown of each roll.

On modern machines, it is customary to have a complete spare set of the rolls above the bottom calender roll, and have these ready to change when the rolls in the operating stack appear to become worn or their surface dull. Since the crown of calender rolls must be absolutely true, it is poor policy to change only one or two rolls and have newly ground rolls put into contact with rolls that have been running in the stack for some time previously. If this be done trouble may occur on the calender stack, because it takes time for the newly ground roll to become fitted to the used rolls. A roll should be allowed to cool before it is ground. Accuracy of grinding may be tested by passing a light behind the stack: no light should show between the nips.

Standard 32-lb. newsprint paper is approximately 0.0032 in. thick, and a small variation in this will cause difficulty with the reels; it may even follow through to the printing press that uses this paper. This may also happen in the case of book or other

printing papers that require accuracy of register on the modern printing press. It is therefore apparent that the accuracy of the crown on the calender stack, and the condition of all calender rolls, are extremely important features in the papermaking process, particularly if printing papers are manufactured.

The bottom roll of a calender is a driven roll. In modern machines that have the electric drive, the turning is done by an independent motor, tied in with the synchronized drive. The rolls above the bottom one are driven by friction, and, when the paper is off the machine, the calender rolls run in contact with each other, which is not good treatment for the surface of the rolls: it should be avoided whenever possible. If the machine is down for any period of time, the calenders are usually stopped, to prevent undue wearing of the surface of individual rolls. Should the paper plug in the calenders, it is also sometimes necessary to stop the calenders and remove the wad. If this is not done, and the bottom or intermediate roll revolves against one of the stationary upper rolls, which may have been stopped by the wad of paper, there is danger that the surface of the upper roll may wear flat, or become burned across its surface in contact with the revolving roll. This problem of operation must be carefully watched by the back tender.

Sometimes faulty bearings cause difficulty in the calender stack by allowing one or more of the individual calender rolls to shift to the front or back side, thus throwing it out of its normal position. This may cause heating of the bearings on one side, which, in turn, will increase the temperature of that end of the calender roll and thus increase its diameter. The effect of this will be a thin area in the sheet at the place of expansion, and the reel will have a soft end. If two rolls become crossed, on account of a bearing slipping out of line with the others, there may be an end thrust that will heat a bearing. Some calender rolls have a hole bored in the end of each journal, thus making it possible to cool off the bearing of the roll by directing a stream of cold water into the end of the roll.

In order to improve the finish on some grades of paper, one or more steam rolls may be used. The *steam roll* has a bored center, and steam is supplied to it in order to increase its temperature throughout the entire length of the calender roll. In some cases, a *water roll* is necessary, this being so made that cold

water can be supplied to it throughout its entire length in a constant stream; consequently, the roll will remain cooler than the adjacent rolls and thus assist in developing a better finish on the surface of the paper.

309. Variation in Finish.—The surface of the paper can be varied considerably by changing the pressure of the calenders and the number of rolls used. Calender frames are fitted with a pair of long vertical screws on either end. One or more rolls can be lifted by pulling up a yoke under each journal of the lowest roll to be lifted, by turning screws whose threads pass through threaded holes in the yokes. As the screws are stationary, except for turning, the yoke acts like a nut; and as it rises, it carries the rolls with it.

On large and modern machines, the old method of lifting rolls by tightening up nuts on the vertical screws is slow and inadequate. Most of the later types of calender stacks are equipped with a roll-lifting device that is operated electrically. The yokes can be placed under any desired calender roll, and the rolls are lifted by a worm-gear and screw device driven by a motor, which is usually located on top of the calender stack. This allows for a quick and easy change in the calendering conditions, in case a smaller amount of calendering is required on a different grade of paper. One or more calender rolls may thus be lifted out of service to give a rougher finish and increase the caliper of the sheet. In order to get a higher finish, some stacks are equipped with a lever and weight system for increasing the pressures between rolls.

For extra-high finish without the use of supercalenders, some machines are equipped with more than one stack. If a rough, antique finish is desired, calenders may be omitted entirely.

When paper is first put through the stack, there may be small pieces of paper stuck to the rolls, and these will mark the paper if not removed. The remedy is to throw some water or kerosene on the stack, or to scrape the paper off with a calender scraper: the doctor blade will take off most of the pieces.

The friction incident to calendering generates much heat; and since this might become excessive, it is customary to cool the calenders with a blast of cold air. The air is led in by a horizontal duct, which extends across the machine behind the bottom calen-

der roll; it is distributed by a set of vertical pipes, from which elbows direct the blast against the calenders.

REELS, SLITTERS, AND WINDERS

TYPES OF REELS

310. Four-Drum Revolving Reel.—From the breast roll to the calenders, the manufacture of paper is a continuous process; but after the paper leaves the calenders, it must be gotten into a form that can be readily handled. To accomplish this result, it is generally necessary to trim the edges and slit the sheet into several strips; and the first step in this process is to wind the paper on a reel. There are a number of types of reels and winders, several of which will now be described.

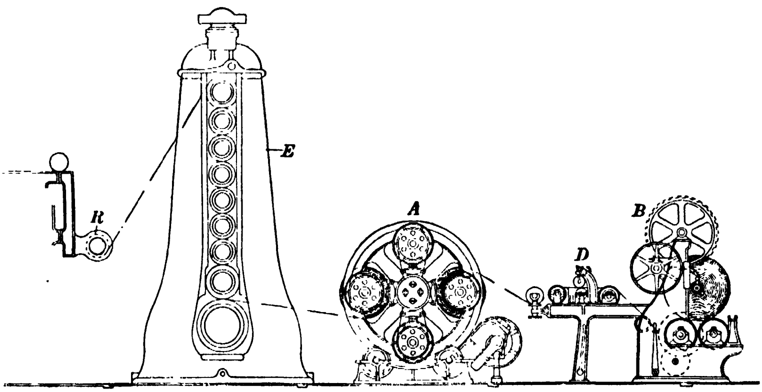


FIG. 99.

A four-drum revolving reel *A* is shown in Fig. 99. Here the paper is wound up on one reel cylinder and is reeled off the opposite cylinder at the same time; this allows the winder to keep up with the paper machine, while giving time for removing a finished roll from the winder *B* and starting another roll. The peripheral speed of the winder rolls must be greater than the speed of the paper through the machine; this is to provide for unavoidable delays in changing rolls, setting slitters, starting the winder, making splices, etc.

311. The English Reel.—A type of peripheral, or surface, drive reel, sometimes called the **English reel**, sometimes the **Pope**

reel, is shown in Fig. 100, the paper being wound around the core by reason of the friction between it and the revolving drum. The large drum *F* is driven mechanically, and it is therefore always turning. An arm *H*, holding a core *K*, with the paper wound on it, is lowered by the wheel and gear *W*, so that the paper on the core rests on the large revolving drum. The result is that the paper and core are forced to revolve around the core bearings, and this winds the paper on the core. The paper roll gets larger and larger, but it cannot wind up faster or slower than the peripheral speed of the large revolving drum. This reel has the advantage of making reel rolls that are tight and uniform, and it therefore helps in making a good roll on the winder.

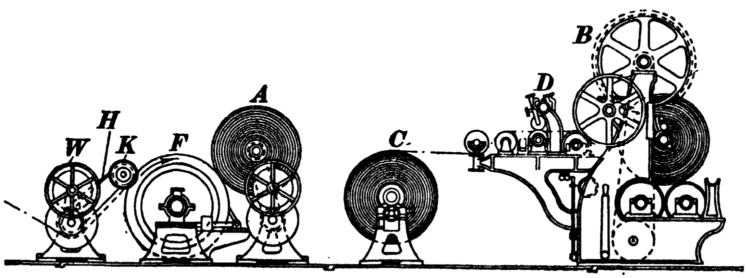


FIG. 100.

Fig. 100 also shows a reeling-off stand, the roll of paper being taken out of the reel at *A* and placed in this stand, ready to run through the slitters and onto the winder. In both Figs. 99 and 100, the reel is shown at *A*, the winder at *B*, and the slitters at *D*.

312. Transferring the Paper.—Skill is required to transfer the paper from the calenders to the reel. On fast machines, when one reel is full, an empty reel is 'struck in,' *i.e.*, connected. The back tender or third hand holds a special sharp-pointed steel instrument or knife against the paper on the last calender roll; this cuts a narrow strip, which his helper pulls off and winds around a new reel, draws tight, and tucks the free end between the sheet and the reel, while the knife is carried across the sheet. The paper is then winding full width on the reel.

On slow machines, the back tender or third hand stands on the front side of the sheet and his helper stands at the back. One man grasps the edge of the paper near the calenders and snaps the paper across, or else he cuts it with a stick that is held in the

free hand. The two men now pass the paper under the reel, catch it on the other side, draw the slack tight, and then tuck it in. The tension of the reel belt is carefully adjusted at once, so the paper draws tight without wrinkling. The full roll is 'struck out' as soon as possible.

When a new roll is built up on a reel that is driven, the tendency is for the surface to travel faster and faster; and since the paper speed is constant, one of two things must happen; the paper must break, or the reel speed must change. The latter may be effected by driving the reel with a belt, the tension of which can be so varied as to allow it to slip more or less.

313. Two-Drum Upright Reel.—A two-drum upright reel is shown in Fig. 101. While the paper is being reeled onto one of

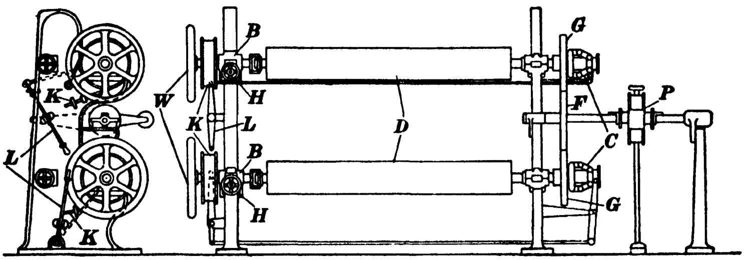


FIG. 101.

the drums from the calenders, it is being reeled off the other drum onto the slitters and winder. The reel is driven by a belt on pulley P; and on the same shaft that carries P is keyed the main driving gear F, which is in mesh with the gears G, G. The driven gears ride loose on their shafts until the clutches C, C are thrown in by the operator at the front side of the machine, by means of the clutch levers L, L. The reel drums D, D can be lifted out of their bearings, when it is desired to use a reeling-off stand or to repair the drums. The front bearings B, B, which carry the driving shaft, are adjustable by means of the hand wheels H, H, to correct for any inaccuracy in the way the paper reels. If the paper tend to travel to one end of the drum, or if it tend to wrinkle, this can be corrected by moving the front bearing forward or back. If the paper is pulling too tight, the tension on the slip belt is lessened a little.

314. Controlling Paper Tension.—When the paper is being unreeled, the operator can control its tension by means of the brakes *K* on the pulleys at the front end of the drum shafts, Fig. 101. The brakes are straps that pass nearly around the pulleys, and they can be so tightened or loosened by means of hand wheels that the work done by the winder is made heavy or light, thus controlling the tension of the paper to the winder and the tightness of the roll. The tension of the paper from the calenders, as it is reeled onto the drums, is also controlled by the brakes, as well as by the tension of the driving belt on pulley *P*.

315. Three-Drum Reels.—A three-drum upright reel is shown in Fig. 102. Since like parts are here lettered the same as

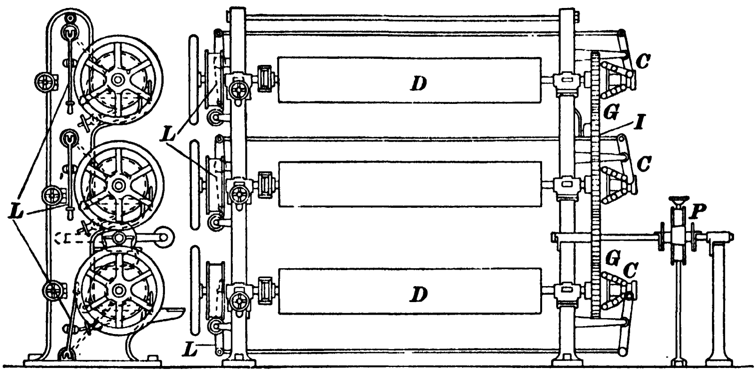


FIG. 102.

with the two-reel drum of Fig. 101, the explanation of the latter as previously given will suffice also for this case. The only essential difference between the two is in the gearing, and an idler *I* is used to gear together the two top-drum shafts. This is done in order to keep the three drums revolving in the same direction when the clutches are in.

The principal advantage in 3 drums is in reducing the chances of having no empty reel when a new roll must be started, should there be trouble with a stripped roll or the winder.

In Fig. 103 is shown a design of a three-drum revolving reel that is similar in details to the four-drum reel shown in Fig. 101. Insofar as is possible, corresponding parts are lettered the same as in Figs. 101 and 102, which show upright reels, and this design may be compared with those. The levers *L* are for the

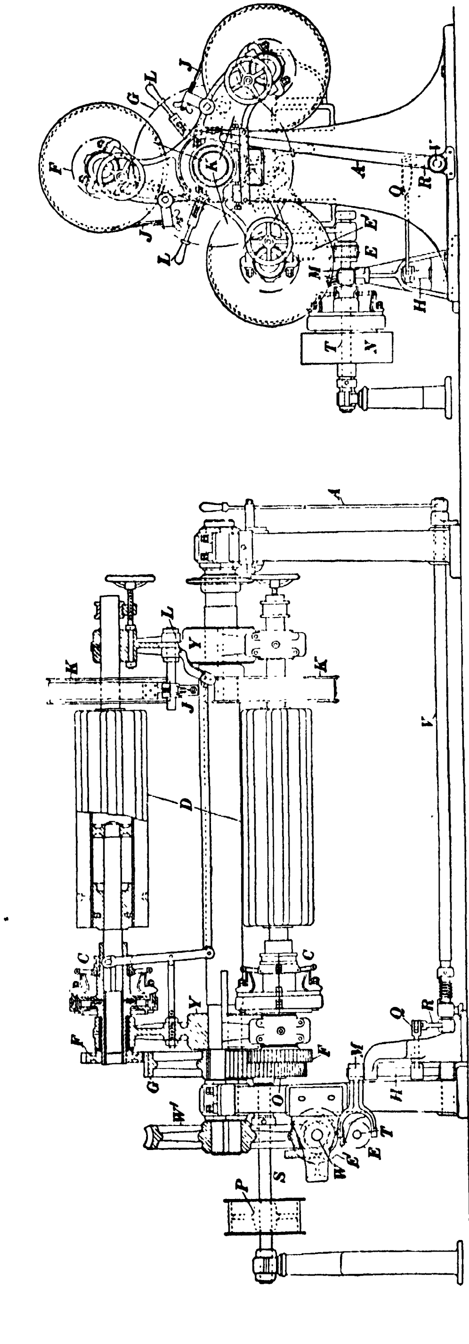


FIG. 103.

purpose of throwing out the clutches C on the drum shafts, so that the gears F that mesh with the large driving gear G will cease to turn the drums when they are not winding paper. Gears F are loose on the drum shaft, but the clutch is keyed to it. The large driving gear G is itself driven by the small gear O, which is on the driving shaft S; the latter carries a pulley P, which is driven by a slip belt. The tension of the paper is controlled in the same way as in the case of an upright reel, by properly proportioning the tightness of the slip belt and the brakes J on the brake wheels K. The slip belt can be tightened to pull the load easily; then the brake is so adjusted that the

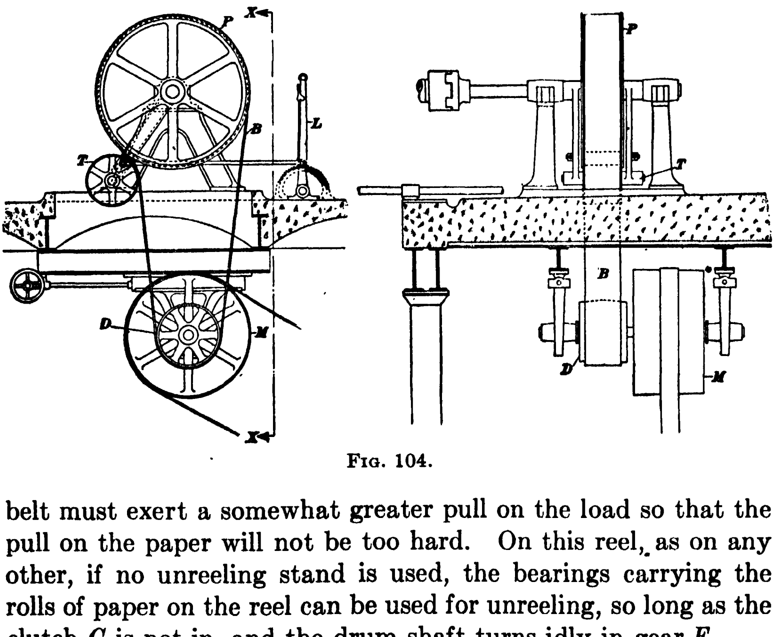


Fig. 104.

belt must exert a somewhat greater pull on the load so that the pull on the paper will not be too hard. On this reel, as on any other, if no unreeling stand is used, the bearings carrying the rolls of paper on the reel can be used for unreeling, so long as the clutch C is not in, and the drum shaft turns idly in gear F.

316. The Slip-Belt Drive.—A type of drive, called a **slip-belt drive,** is shown in Fig. 104; it illustrates the principle of the drive that is used on the older types of mechanical reels and winders. The tension of the driving belt B and the amount of lap around the driven pulley P may be varied by means of a tightener. When the tightener T is out altogether, the belt hangs idly on the top, or driven, pulley P, and the bottom loop does not touch the driving pulley D, which therefore turns idly. Pulley

M is keyed to the same shaft as pulley *D*, and is driven from the variable-speed shaft or by a motor. As the tightener is pulled in by the action of the lever *L*, the lever being held in position at any point that gives the required belt tension by means of the quadrant and pinion shown, the tension of the belt can be varied from nothing (in the idle position) to the maximum tension that the operator can give it. When the belt is comparatively loose, it slips on the driven pulley; in such case, the speed of the reel drums *D*, Fig. 101, is slow, the tension of the paper is slight, and the tightness of the brakes *K* is small. By tightening the driving belt, the machine tender can increase the pull by the drums on the paper from the calenders; but should the tension get too high, he can correct this by tightening the brake straps *K*.

317. Unreeling, or Reeling-Off, Stands.—An **unreeling stand,** also called a **reeling-off stand,** is shown in Fig. 105; an unreeling

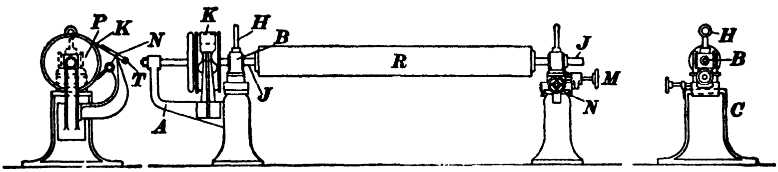


FIG. 105.

stand is always used with the friction type of reel. The reel drum, with its roll of paper *R* on it, is taken off the reel by use of a compressed-air or electric hoist, and it is placed in the bearings of the unreeling stand. An unreeling stand is never driven, since the paper is pulled off by the winder. As the roll on the winder grows larger, the roll on the unreeling stand grows smaller, and the tension of the paper between the two varies greatly. The brake *K* is used to control the paper tension by means of the thumb nut *T*, whenever the winder man wishes to alter it. If the tension is kept fairly uniform, the re-wound roll is kept hard all the way through. The position of the reel drum is so adjusted by the hand wheels *M* and *N* that the paper will run true to the winder.

318. The Brake Bands.—The brake bands on unreeling stands and reels are subjected to very severe service when they are controlling the tension of the paper to a high-speed winder, say when winding the paper at a speed of 2000 feet per minute,

more or less, and the high speed of the pulley within the stationary brake band will soon burn out a leather strap. These pulleys should be very wide and large in diameter, so as to have ample brake surface. A pulley of large diameter will have a high peripheral speed when revolving swiftly, but it takes less force to slow it or stop it.

WINDERS AND SLITTERS

319. Types of Winders.—The unreeling stand, slitters, and winder are virtually a single unit, located behind the calenders and reel to re-cut the paper being made on the machine to the various sizes of rolls required by the customers, or for further processing in the finishing room. The winder operating speed is usually two or three times that of the paper machine; thus it is possible to more than keep up with the production, make splices (if necessary), change slitters, or otherwise operate the winder in an intermittent manner.

Since the full-width reel is transferred from the machine to the rewinding stand, it is possible to slit or cut the reel into any width of rolls that may be required, by setting the slitter knives or revolving disks so that the paper is cut or slit in its travel from the unwinding stand to the roll being built up on the core or winder shaft. The slitter knives also trim the outer edges, the trimming being returned to the broke beater.

Winders are usually designed for some specific type of paper and width of machine, but all operate in fundamentally the same manner. For a fast newsprint machine, the winder can operate at speeds up to 3000 or 3500 ft. per min. and produce a roll of paper up to a diameter of 40 in., though the average is nearer 35 in. The modern kraft machine is capable of operating at about the same speeds, but will make a roll of even larger diameter and cut up the reels into more individual rolls. There are two major types of winders: the shear-cut winder; the pressure- or score-cut winder.

The **shear-cut winder,** illustrated in Fig. 106, is a type widely used in the modern paper mill. The paper passes from the unwinding stand *S*, through the tension rolls *T*, the upper and lower slitter disks *D* and *E*, over the other rolls and the spreader bars to the two winding drums *W* and *W′*. The sheet is wound

around the paper or fiber core on shaft *F*. As the paper starts to build up on the winder, it is tightened up to some extent by the *rider roll R*, which rests on top of the rolls of paper being wound. When the rolls are wound to the proper diameter, the winder is stopped and the rolls are forced off by kicker arms onto the lowering arms *L*, which let the paper roll down to the floor level.

In this type of winder, the slitters are some distance from the actual roll being wound, and there is a considerable draw between the point where the sheet is slit and the shaft *F* where it is wound up. This requires careful attention to the adjustments

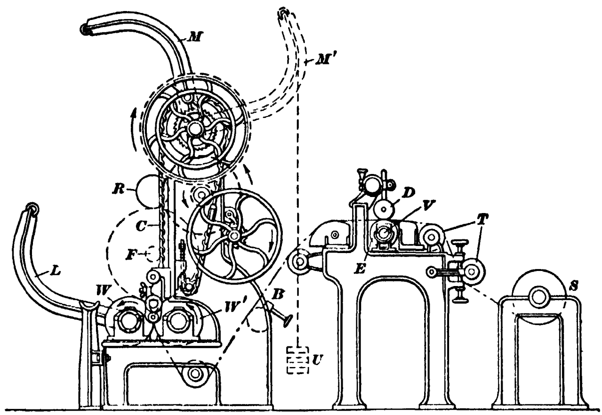


Fig. 106.

that keep the sheet running true, and to prevent edges of the rolls from running together. The arms *M* and weight *U* serve to counterpoise the weight of the rolls as they build up.

The **pressure- or score-cut** type of winder has the slitters located immediately under the winding rolls, so there is practically no draw between the point where the sheet is cut and where the paper goes onto the winder shaft and core. The slitter knives on this type of winder have a smooth but semi-rounded edge, which is pressed against the paper as it runs over a hard roll. The pressure of the slitter disks can be adjusted by springs, so that a *crease* (score) cut is made, and the sheet is properly slit at the point of contact.

In either type of winder, it is customary to have the winding drums of the grooved worm type, which keeps the paper flat

and does not allow it to wrinkle. Further, it is also customary to have a differential in speed between the two winding drums, so that the front-side drum is operating a little faster than the back drum: this makes it possible to wind up a very tight, smooth roll.

Modern winders are usually driven by an electric motor; frequently both winder drums are driven by separate motors. On many machines it is possible to use the so-called constant-speed motor, though a much more satisfactory arrangement is to use a slip-ring motor of adequate capacity, with a drum controller to accelerate in speed as may be required. Many new installations have direct current available. This type of drive enables the operator to increase the speed as desired. With direct current it is possible to use a small motor-generator-combination unit on the unreeling stand to act as a *brake*, which also regenerates a small amount of power. With this type of electric brake, it is also customary to have a mechanical or foot brake on the winder drum and drive, for closer control and to supplement the electric brake. Should the paper break in passing through the winder, it is essential that the winder be stopped very quickly, in order to avoid waste of paper; hence, an adequate method of stopping the winder is very important. On wide, high-speed machines, the dissipation of heat in a mechanical brake is a problem, and may involve considerable maintenance.

320. The Slitter Disks.—Two views of the slitter disks *D* and *E* are shown in Fig. 107. The horizontal distance between the adjacent slitter disks is obtained roughly by turning the hand wheel *H* (or a set screw), so that clamp *C* is securely fastened to the cross shaft *Z* that extends across the machine and holds all the slitter clamps. The vertical position of each upper slitter disk is determined by means of the hand wheel *W* (or a set screw) and clamp *K*. The position of clamp *H* is such that when lever *L* is in the position shown, disk *D* is pressed against the revolving lower slitter disk by spring *S*. When the top of lever *L* is thrown over to the left nearly 90° from the position shown, the face *A* of the bell-crank lever is forced against the annular flange *B*. This pulls the slitter disk *D* away from the lower disk, and compresses spring *S*. When lever *L* is returned to its original position, spring *S* pushes disk *D* back to the position shown in Fig. 107.

The lower disk E is made fast to the slitter shaft V, Fig. 106, at the proper point for slitting the paper.

The lower slitter disks are rings of cast iron or steel, turned on the outside and faced on the end touched by the upper disk, thus

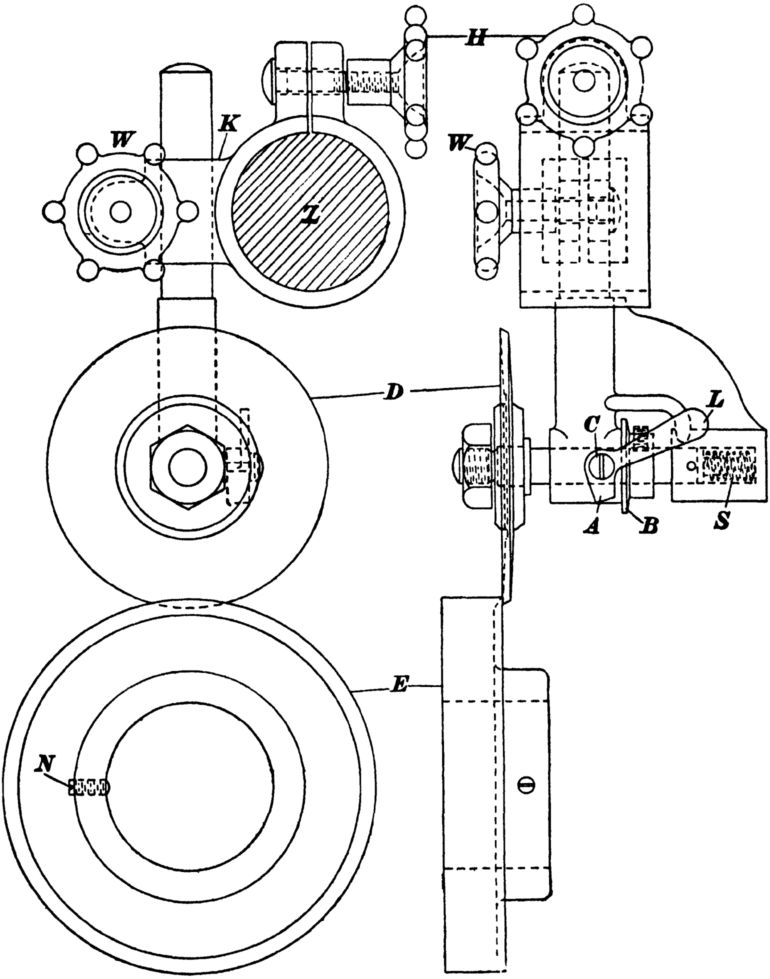


FIG. 107.

giving a sharp edge for the upper disk to work against. The lower disks are clamped on the slitter shaft, or else they are fastened on it by headless set screws N. The slitter shaft is so driven that it revolves just fast enough to insure the proper speed

to the edges of the slitter disks. When the upper slitters are brought into contact with the lower ones, the springs S exert sufficient pressure to cause the upper slitters to revolve at the same speed as the lower slitters. When the slitters are not in contact, the paper passes over the lower slitters and under the upper slitters without being cut. On high-speed machines, it is better to have large lower slitter disks, 8 or 10 inches in diameter.

Slitter disks should be kept sharp, and their edges should travel at least 10% faster than the paper; if their speed is slower, or is about the same as that of the paper, they will not cut clean. The lower slitter disks should be so placed that they project above the slitter board not more than $\frac{1}{16}$ inch.

The shavings usually fall clear of the slitter, and can be blown through pipes to a broke beater below; or they may be carried by compressed air to the tending side and put in a broke cart.

321. Operating Slitters.—If the top shaving slitter is set too far back of the center of the bottom slitter, the shaving will have a tendency to throw up and forward, following the sheet. If it is set too far forward, the shaving will have a tendency to throw down. The best set for a shaving is as near the center as possible.

The proper care of the *bottom slitter shaft* is very important. Owing to its length on the modern winder and the speed at which it is driven, deflection of the shaft and the consequent vibration are very likely to occur. The effect would be to cause the slitters near the center of the shaft, where the deflection would be greatest, to run eccentric; that is, the point of contact with the top slitters would be irregular. Some high-speed winders are equipped with a small motor for each bottom slitter roll, thus eliminating vibration and difficulties due to a deflection of the slitter shaft.

The function of the *slitter board* is to present a flat, even surface, directly in line with the cutting set of the slitters, so the paper may be as free as possible from the influence of the revolving rolls at the cutting point. For paper of ordinary weight, the slitter board should be set exactly level with the rolls immediately before and after the slitters. The top of the bottom slitter is then usually $\frac{1}{32}$ to $\frac{1}{16}$ inch above the board. For heavy papers, owing to the extra friction used in winding, there is a

greater downward pressure exerted on the surface of the slitter board, and it is advisable to set the board slightly low, so that the rolls may take up the extra pressure thus created.

322. The Score Slitter.—The principle involved in the score- or crease-cut slitter is shown in Fig. 108. Here A is the roll of paper to be unreeled and re-wound; P is the re-wound roll, which rests on the winder rolls W_1 and W; G is a guide roll; and S is the cutter. Winder roll W_1 has its surface hardened. Cutter S has a V-shaped edge, and is held against the hardened winder roll W_1 by strong springs; it cuts the paper by *scoring* it, instead of by shearing it, as in the case of the slitter described in Art. **320.** The paper passes from roll A over the guide roll G, between the

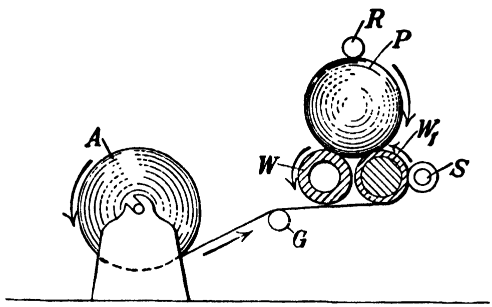


FIG. 108.

score cutter S and the winder roll W_1, and then onto the paper roll P, where it is wound up. The small rider roll R is for the purpose of straightening and tightening the roll when first started. Sometimes a separate cutter roll, for the score cutter to press against, is used. As before stated, these slitters cut the paper by scoring it; and clean, straight-cut, and well-separated rolls are obtained.

323. Operating Winders.—The slitters and the winder drums are usually supported on the same frame. As it leaves the slitters, the paper passes over the spreader bar, which presents a smooth, rounded surface to support the paper. The height of the bar can be adjusted to suit the run of the paper, by moving the brackets either up or down, and by adjusting the hand screws at either end. The inclination of the paper to sag or to vibrate vertically can thus be corrected. The bar is bent, so it will lift

the paper at the center slightly and separate the strips, thus keeping the edges from interlocking while winding into rolls.

The operator passes the paper under the winder and up between the winder drums *W* and *W'*, Fig. 106, one or both of which are usually driven. The paper is then wrapped around the cores, with notched ends, which slip over a core shaft *F*, and are held in position by collars. Shaft *F* is carried in the bearings shown, which are attached to the free end of the chain *C*. The bearings open on hinges, which enables the cores to be slipped over the core shaft. Wooden cores have square holes and fit over a square shaft. Dotted lines show the relative position of parts when the roll is full size.

The arrows show the directions in which the winder drums revolve. It is important that the end drum of the paper machine shall revolve outward on top, to guard against the danger of a man's hand being drawn under the paper roll.

324. The Winder Drive.—The winder is usually driven independently of the paper-machine drive, in order that the starting and stopping of the winder may not cause variations in the speed of the machine and in the weight of the paper, and so the winder may be operated when the machine is stopped.

As the paper roll winds up, it increases in diameter. But since the paper here winds because of its contact with the surface of the winder drums, the paper rolls are kept tight. The paper also winds at a constant speed, for which reason, this type of winder drum is called a **constant-speed winder.**

325. Variable-Speed Winder Drive.—On high-speed winders it is advantageous to be able to start up the winder at a slow speed, gradually increasing it as the roll starts to build up. There are two general types of electric drive, both of which function in a satisfactory manner.

Direct current is used, if available, since with this type of drive, it is easily possible to get the variation of speed that is required. On some direct-current drives, a motor-generator unit is used on the unreeling stand, and this acts as an electric brake whenever it is necessary to stop or retard the reel that is unwinding. It is generally customary to have a mechanical brake on the winders as well as the electric brake apparatus. The dissipation of the

heat generated in a mechanical brake on a wide, high-speed machine is a real problem.

An alternating-current motor can also be used, together with the drum controller, in order to get a series of step-ups in speed when the winder is started. Usually, the drum controller is capable of giving twelve to sixteen variations in speed, which enables the operator to handle his winder satisfactorily.

326. Maintaining Constant Pressure on Drums.—As the roll of paper builds up and increases in weight, the pressure on the drums becomes greater: this, in turn, increases the hardness of the winding and, in some cases, it creates such a pressure that the roll becomes too tightly wound. To compensate for this, some winders are equipped with a lifting device (*C-M-U*, Fig. 106) attached to either end of the winder shaft. A series of weights and levers are so arranged that, when the roll builds up, a certain lift will be exerted on the ends of the shaft, to relieve the pressure to some degree. This device is not well suited to wide machines, since a pull on either end of the shaft is not sufficient to lift the middle of the roll.

Other methods are used to lift the shaft and relieve the pressure on the drums; but, in most cases, the practical method of handling the winder is to allow the roll to build up naturally and support the full weight of the paper being wound.

327. Rider Rolls.—Many of the newer winders are equipped with the so-called **rider roll** *R*, Figs. 106 and 108. This is a small roll about 12 in. in diameter, which is let down on the paper immediately after it has been turned around on the core. The rider roll helps to maintain a pressure, and it gives a better start than can be had on a winder without such roll.

Some winders have a rider roll that is provided at either end with counterweights, and, as the roll of paper increases in diameter, the rider roll will be gradually lifted off the paper. In some cases, this is automatic, but in others, the operator merely turns the hand wheel that lifts the entire roll off the roll of paper being wound.

328. Removing Rolls from Winder.—On many grades of paper used for printing purposes, the reel on the paper machine is built

up to the correct diameter to form the finished roll of proper size. Hence, when the wound roll has used up all the paper on the reel, it is usually within a fraction of an inch of the desired diameter.

On some grades of paper, the reel is built up to a size that will make a certain number of finished rolls. The paper is then cut off on the finished roll, so the end can be placed around the new core without threading the sheet through the winder. This is done when small-diameter rolls, such as counter rolls, are made on a winder.

When the roll has been wound to the correct diameter, the winder is stopped and the shaft is released from its bearings by lifting up the top half of the hinged bearing that holds the winder shaft. This movable bearing is then lowered out of the way, and the wound rolls, with the shaft still in them, are ready to be removed from the winder. On some large winders, this is done by means of kicker arms operated by compressed air. The rolls are then lowered to the floor by movable arms, lowered by means of some type of hoist, or rolled down to the floor level or rolled upon a truck or conveyor. The shaft is then removed and the rolls separated and placed on supports. The shaft is fitted with cores of the right size, which are tightened up firmly by means of collars to prevent slipping, and it is then ready to be put back on the winder.

329. Making a Splice.—When there is a break in the paper being wound on the reel, or when the paper breaks on the winder, a **splice** must be made, so the sheet may be one continuous web. This is especially applicable to papers used on printing presses, though it is general practice for any roll of paper to leave the winder in a continuous sheet.

If the break is in the reel, it is often necessary to make what is called a **reel splice.** The paper is cut just ahead of the splice on the reel, the break is torn off to good paper, and the two ends are spliced with **splicing tissue.** The end of the sheet on the reel is first torn off square, the splicing tissue placed on top of the sheet close to the edge, and the end of the paper toward the winder is pulled tightly across the splicing tissue. The splice is ironed down with a hot flatiron, at about 275°F., and is allowed to cool for a few minutes. The top sheet is then creased as close as possible to the splice, and torn square across the reel. The

winder is then started up, the paper goes onto the rolls, and is wound up in one continuous length.

330. Second Type of Splice.—Another type of splice is known as the **winder splice.** If the break occurs on one of the several rolls being made on the winder, it is necessary to tear down all the rolls across the winder until they are level, *i.e.*, all are of the same diameter. The paper is then torn either square across or slightly diagonal, the splicing tissue is placed on the torn end, and the other sheet is pulled up over smoothly and tightly, then ironed out and torn off in a manner similar to making a reel splice.

Although the so-called 'rubber' or splicing tissue is largely used, other splicing tissues and adhesives are also available, one being a transparent adhesive tape, which makes a splice that is

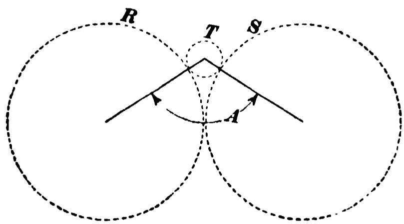


FIG. 109.

almost invisible. Care must be taken in splicing to have the correct temperature, in order to get proper adhesion between the sheets. If the paper in going through the printing press passes over heated rolls, it is necessary to use some type of glue or other adhesive that is not affected by heat. For some types of coarse papers, ordinary paste may be used for making splices.

331. Angle between Paper Core and Winders.—Referring to the diagram, Fig. 109, R and S represent the winder rolls, and T the paper roll at the beginning of the winding. Drawing lines from the center of T to the centers of R and S, they form the angle A. As the roll increases in diameter, the center of T rises, and the angle A decreases; in other words the angle A is continually varying with the size of the paper roll. Under these circumstances, it is evident that the larger the angle A the greater is the grip between rolls R and S and roll T. For heavy paper or pulp, the angle A should not be less than 115°; for lighter papers, say up to 30-pound news, angles a few degrees smaller can be used successfully. It is an advantage to be able to vary the distance

between the centers of the winder rolls R and S, so as to have some control of the gripping effect of the revolving drums, as applied to the surface of the paper roll.

332. Grooved Rolls.—Perfect conditions are required to obtain a 'bull's-eye,' as the machine tender sometimes calls a perfect winder roll. A winder that works well with one paper and has no adjusting devices may not work well with another paper. Grooved winder rolls are used in the majority of winders. The grooves are parallel to the axis of the roll or inclined to form an angle pointing in the direction the roll is traveling. This will enable the papermaker to obtain better winder rolls than with the ordinary ungrooved rolls. The grooved roll tends to offset the bad results due to faulty design in spacing and in crowning of the winder rolls. When a winder is designed for universal service, a grooved roll is an advantage. The grooves further assist in separating the rolls and in preventing interwinding. Winder rolls should be crowned just as carefully as lower press rolls.

The angled grooves cut in the drum and running from the center to each edge have very important duties to perform: (1) The angle at which the grooves are cut smooths out the surface of the paper. This action tends to smooth out slack places caused by soft spots, prevents wrinkling, and presents an even surface uniformly hard. (2) The grooves give the drum a harder grip on the paper than a smooth drum. The higher the finish on a sheet of paper the more evident is the gripping power thus created.

333. Other Types of Winders.—The details and operation of the winder shown in Fig. 106 are typical of all winders, but the different makes exhibit various characteristics. One make, for instance, has drums of unequal size; thus, the drum corresponding to W in Fig. 106 is 28 inches in diameter, while that corresponding to W' is only 12 inches in diameter. The larger drum carries the greater part of the weight of the roll, and its size gives it greater contact with the paper. The drums are so grooved that the rolls do not run together, and the small drum is protected by a guard, which is automatically kept at a constant distance from the paper. The guard is desirable, because the paper is brought up behind the second roll, not between them, and the drums therefore turn in a direction opposite to that indicated on Fig.

106. Instead of the chain lift on the core-shaft bearings, the winder-shaft bearings are attached to the lower end of racks, which mesh with pinions that are operated simultaneously by worm gears. The racks run through rigid guides, to take up the end thrust on the winder shaft. On these winders, ball bearings are extensively used.

334. Four-Roll Winder.—An important development of this type of winder is the use of four drums and several core shafts. This prevents entirely the interwinding of rolls, since no two rolls are adjacent. The shafts are short, and they are confined at the outside ends, to take care of the side thrust. A great advantage of this design is that, if there be a streak or defects in one part of the sheet, the defective paper may be cut off from *one* roll, something that is impossible with a two-drum winder, since the paper on one roll would not be pressed against the winder, in that case, and a poor roll would result.

335. Compensating Winder.—On paper machines, the *compensating winder* has largely been supplanted by the constant-speed type. The former (older) type is still in common use on board machines. The main principle that governs its design is to have a set of core shafts, usually 2 or 4, driven through a set of spur and differential gearing. The difficulty attending its operation is that the core shafts run at constant speed; thus, as the rolls grow larger, the speed of the paper increases until it becomes very great, which often causes trouble in winding. It is also difficult to have the rolls uniformly solid.

336. The Cutter.—On high-grade tub-sized and air-dried writing papers, it is sometimes customary to cut the paper into sheets just after passing through the size tub. With papers that are dried and calendered on the paper machine, the cutting may also be done in the machine room, as the paper comes from the slitters. Where the paper is to be sized in the full width of the sheet and cut in the finishing room, it is dried by an auxiliary nest of five or six drying cylinders, or by one of the systems of air drying described in *Sizing of Paper*, Vol. IV.

The advantageous use of a cutter here depends on the weight of the paper and the length of the sheet to be cut. The cutter knife can make only a certain number of revolutions per minute effectively and efficiently, and it can operate more rapidly on

relatively thick than on thin papers, since the sheets are then delivered and piled better, as they are cut. The longer the sheet the faster is the paper taken from the reel, and, hence, the greater is the possible speed of the machine. If the cutter is making 70 clips per minute on 24 × 36 inch sheets, the long side being with the grain, the possible machine speed is $\frac{70 \times 36}{12} = 210$ feet per minute, which would be a fair speed on heavy book or wrapping paper. The cutter, which is combined with an automatic piling device, or lay boy, is fully described in the Section on *Sizing of Paper*, Vol. IV.

WINDING TROUBLES

337. Variable Tension.—At the start of the winding, the tension, or pull, on the paper is light, and it is adjusted by the brake band on the reel or unwinding stand. As the winding speed increases, the tension increases gradually, until the paper is winding tight and hard. In order to get a good hard center, it is necessary to maintain the correct tension and get a smooth start during the first few revolutions of the shaft. When the outside gets hard, as the roll builds up, there is almost a certainty of trouble with slipped rolls if the center is soft or loosely wound. With compensating winders, the speed becomes terrific as the end of the roll approaches; and after the halfway point, it is necessary gradually to reduce the tension of the brake bands, and, in some cases, even to let the reel run loose.

338. Wrinkles.—**Wrinkles** may originate at the reels or at the winder. If the fault is with the paper before it goes to the reel, it may be difficult to eliminate the trouble at the winder. The tension, rider roll, and speed should be adjusted in the best possible manner to compensate for a poor reel.

339. Curled Edges.—With compensating winders, one edge of the roll may display a tendency to curl and to run higher than the body of the roll. As the reels build up, such an edge will crack. The slitters may be dull, or they may run too slowly. The upper slitter may be so set that it overlaps too much on the lower slitter. The temporary remedy is to lean a board or plank against the high edge, thus retarding the increase in diameter of the roll at this point.

340. Slipped Rolls.—When a roll is wound loose at the center and is thus harder on the outside, it is likely to slip sidewise; or a portion of the roll may slide out, especially if one side of the roll is softer than the other by reason of uneven thickness of the paper. The usual remedy is to attach a clamp on the core shaft, to hold the center of the roll in place, and it is best to bolt the clamps fast when the machine is stopped. The two parts are sometimes fastened together loosely around the shaft, slipped into position, and held there by winding a cord around the shaft and against the roll clamp.

341. General Operation of Winders.—Paper-machine operation in general has a fairly distinct allocation of responsibility. The machine tender takes care of the wet end of the machine, and makes any adjustments that are required for the satisfactory operation of that part of the machine. The back tender's duties are usually to take care of the drying, calendering, and reeling of the paper. His duties are to make the proper adjustments of the equipment used to make the right sheet of paper. The machine tender has supervision over the back tender, of course, but he generally has sufficient duties of his own without spending too much time at the dry end of the machine, particularly on modern high-speed paper machines.

The third hand's duties are largely to operate the winder and make the finished rolls ready for the wrapping or finishing departments. Since this is the final operation in papermaking, his responsibility is just as great in degree as that of the machine tender or back tender. This is particularly true in connection with the modern high-speed winder making rolls that are not further processed but go direct to the large publishing houses and newspaper pressrooms. These rolls must be as nearly perfect as possible; and the third hand, who has charge of the winder, must not only direct his assistants, the fourth and fifth hands, should there be two helpers, but also make sure that the winder is properly functioning to produce the perfect roll.

Assuming that the winder is kept in good mechanical condition by the repair department, perhaps one of the most important duties of the winderman is to watch the condition of the slitters and slitter rolls. It is essential that these disk slitters be kept sharp, particularly on the score-cut winder. The springs that

hold the slitter against the slitter roll must be properly adjusted. When the size of the roll is changed, it is very important that the winderman check the setting of the slitters. If a mistake is made in the slitter setting and the roll is slit, say, one-quarter inch too wide or too narrow, it invariably results in complaints from the pressrooms and printing establishments where the paper is used. If the paper is to be further processed, it is also important that the rolls be made the correct size, both in width and diameter.

A hard or tight start is necessary in producing a well-wound roll on the winder. The cores must be true and well set up on the winder shaft, so there will be no slack edges. The first essential is that the cores on the shaft present a true cylinder on which the paper is to be wound up. Probably the most important feature in winding is to maintain the correct tension on the entire reel as well as on the individual rolls. The adjustment of the spreader bars and the regulation of the tension brakes on the unreeling stand are most important features for the winderman to control.

Since a roll from the winder is in one continuous web, the importance of 'putting up' a good splice cannot be emphasized too strongly. On many high-speed newspaper presses, no attempt is made to slow down the press when a splice goes through, since the spliced sheet is considered to be just as strong as the rest of the paper in the roll. Some pressrooms specify that the splices should be *flagged*, and they slow down the presses to some extent when coming to a splice. If the paper is used for processes other than for printing, a splice is of less importance. Still, it is the winderman's responsibility to make a satisfactory splice.

342. Variables on Calenders and Winders.—Since the making of the paper is virtually complete when it reaches the calender stack, there are fewer variables at the dry end of the machine than there are at the wet end. However, they are more important, perhaps, since the final finish of the paper by the calenders and the winding of the rolls furnish a last opportunity for changing any conditions affecting the finished product. Some of the conditions governing the grade, type, and quality of the paper are:

1. Number of calender rolls in the stack.
2. Type of materials used in the calender rolls.
3. Diameter of each roll.

4. Crown of the individual calender rolls.
5. Temperature of the individual calender rolls.
6. Comparative temperature across the stack.
7. Pressure gradient between calender rolls.
8. Maximum pressure on calender-roll stack.
9. Slippage between the calender rolls.
10. Tension on sheet between calender and reel.
11. Condition of winder slitters.
12. Adjustment of slitters, slitter disks, and slitter rolls.
13. Type of winder shaft and cores.
14. Type of winder drive.
15. Tension-control equipment on unwinding-stand winder.

There are other variables on machines equipped with two calender stacks, making steam- or water-finished paper, a sized or calender-colored sheet, or other special calendering operations. The use of the sweat roll and similar equipment is a special study in itself, depending on the particular grade of paper made.

PAPERMAKING MACHINES

(PART 4)

EXAMINATION QUESTIONS

1. What is the purpose of the spring roll at the calender end of the dryer part?

2. (*a*) Why is the calender dangerous? (*b*) How may accidents be avoided?

3. Explain the purpose and action of the calender.

4. Describe a calender stack, and state the course of the paper through it.

5. (*a*) What is the effect, as regards calendering, of too much, too little, or just enough moisture in the paper? (*b*) How can the moisture content be controlled?

6. Mention some calender troubles, their causes, and their remedies.

7. (*a*) Why is the bottom calender roll crowned? (*b*) Give reasons for the various sizes and crowning of the different rolls in the calender stack.

8. Explain how the finish of the paper is affected by the calenders.

9. (*a*) Why is a reel necessary? (*b*) What are the principal types?

10. Describe what you consider to be the best type of reel, and explain why you consider it superior to any of the other types illustrated.

11. How is the tension of the paper controlled during winding?

12. Explain the principle governing the operation of each of two types of slitters.

13. Describe the two-drum winder.

14. How does the four-drum winder differ from the two-drum type, and why are both better for most purposes than the compensating shaft-driven winder?

15. What is an unreeling stand, and why is it used?

16. (*a*) What causes a slipped roll? How is it checked (*b*) on the reel? (*c*) on the winder?

17. (*a*) What is done in case of a break in the paper being wound? (*b*) Describe one way of making a splice.

18. Mention the duties of the third hand and discuss them.

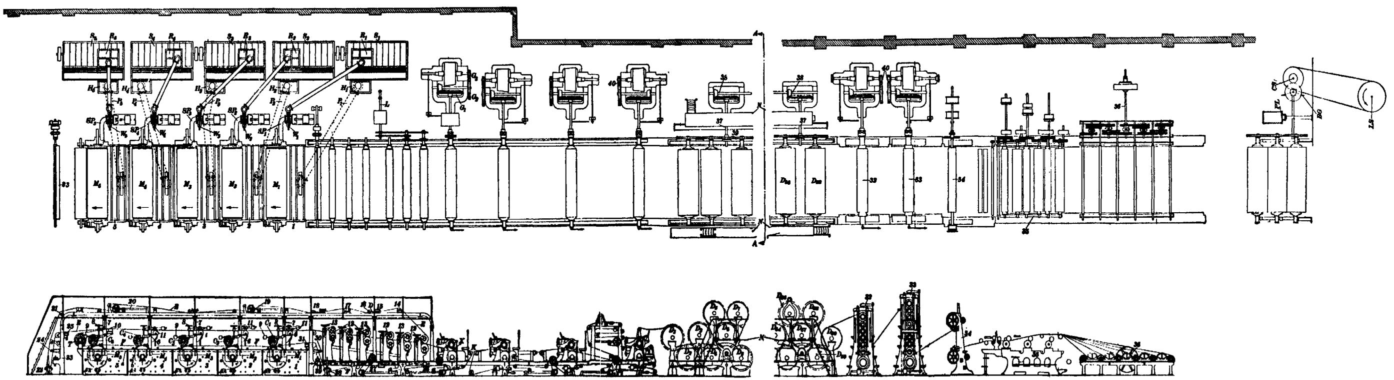


FIG. 110.

(Facing p. 247, §1)

SECTION 1

PAPERMAKING MACHINES

(PART 5)

BY J. W. BRASSINGTON
REVISED BY ARNO W. NICKERSON

SPECIAL PAPER MACHINES AND PAPER CALCULATIONS

THE CYLINDER MACHINE

THE WET END

343.—Vats and Molds.—The **cylinder machine** was invented by John Dickinson, of Croxley Mills, England, in 1809; it was probably introduced in the United States before the first Fourdrinier machine appeared in America. The **cylinder vat,** together with the **cylinder mold,** is the leading characteristic of this machine. In Fig. 110, the cylinder machine there illustrated has five vats, numbered from 1 to 5, and the molds are designated by M_1 to M_5. The number of vats varies, some machines having only one vat, while the largest ones may contain as many as twelve.

The cylinder molds are covered with wire mesh, and as they turn, they strain the fiber from the water and pass it to the felt F. The water thus strained is drawn off from the vats through pipes SP_1 to SP_5, as will be more fully described later.

The general principles of paper formation on cylinder machines are exactly the same as those applying to the Fourdrinier machine. The best sheet is formed on either machine by using the largest amount of water *that can be safely handled.* Modern machines are continually being improved so as to handle larger and larger quantities of water satisfactorily. It is also true that the sheet,

as formed on the wire or wires, can be only slightly improved by subsequent handling but may very easily be harmed. Modern practice attempts in every way to form the sheet on the wire in the best possible manner, and to maintain the good qualities through the suction and other parts of the machine. Much progress has been made recently in this regard.

344. Circulation of Stock.—It will be well to consider the circulation of the stock at the wet end of the machine before taking up the various parts in detail. Referring, therefore, to Fig. 110, R_1 to R_5 are regulating boxes, which are similar in design and purpose to the regulating boxes used on a Fourdrinier machine. As usual, the stuff pumps discharge from stuff chests into these regulating boxes, and there is an overflow to the stuff chest. The white-water centrifugal pumps W_1 to W_5 suck the white water from the inside of the cylinder molds and then discharge it into the corresponding regulating boxes. Note that the circulation of the stock is separate and self-contained for each cylinder vat and mold; for instance, vat 1 may have a fine stock, say blue colored, while vats 2, 3, and 4 may contain wood-pulp stock, old papers, and so on, each vat being supplied with the desired stock, without interfering in any way with any of the other cylinder vats and molds. The last vat, in this case vat 5, may also have a relatively fine stock, which may be of any color. The final sheet of paper is made up of stock from all the vats, and will contain as many layers as there are vats in use. The outside layers, which are formed from stock from the first and last vats, are called **liners**; the intermediate layers are called **fillers.** The paper so made is called **board,** and it is named according to the character of the fillers and liners, as white-lined, newsboard, etc.

In each case, the diluted stuff (stock) flows from the regulating boxes to the screens S_1 to S_5, in exactly the same manner as in the case of a Fourdrinier machine. From the screens, the screened stock flows to the headboxes H_1 to H_5, in which the liquid (stock) is kept at such a level that the flow through the pipes P_1 to P_5 will keep the stock in vats 1 to 5 at the level desired by the machine tender. The stock in the vats sticks to the wire of the revolving cylinder molds, while the water (white water), as in the case of the Fourdrinier machine, goes through the wire mesh to the suc-

tion pipes SP_1 to SP_5, and is returned to the regulating box for the purpose of diluting more stuff.

345. The Cylinder Molds.—The cylinder molds M_1 to M_5 are only partially immersed in the stock. The levels of the stock in the vat and of the water in the molds are indicated by the dotted lines above the journals, and the direction in which each cylinder mold turns is shown by arrows. As the cylinder molds come up out of the stock, the wire mesh is covered with matted fiber and filler, which is in much the same condition as the pulp on a wet-machine mold, or as the paper on a Fourdrinier wire after it passes the first suction boxes. This partially formed wet paper meets the lower felt F, which is pressed against the cylinder mold, in each case, by the couch rolls C_1 to C_5. Now when wet paper, particularly paper in this condition, is brought into contact with two surfaces, it will *always stick to the smoother surface;* it does this because there are more points of contact between the paper and a smooth surface than between the paper and a rougher surface. Since the surface of the felt is smoother than that of the wire mesh covering of the mold, the felt F picks the paper off the mesh of mold M_1, the paper sticking to the under side of the felt with sufficient force to withstand the pull of gravity. The wet paper then picks off another layer from mold M_2 as the felt passes it, the surface of the wet paper being smoother than wire mesh. As the felt passes mold M_3, it picks off a third layer, and so on until the felt has passed the last mold, in this case, mold M_5.

346. Number of Layers in the Board.—It will now be evident that this cylinder machine can make a board 5 layers thick. The first and last layers, the liners, are composed of materials best suited for the outside in color and finish, while the interior layers, the fillers, may be composed of less expensive stock. This machine can make tissue paper by using only one vat and mold, if the dryer nest were suitable; and it can make any combination of different qualities of paper, being limited in this respect only by the number of cylinders and the quality of the prepared stock.

For such papers as roofing felts, which have to be saturated, it is customary to use only one cylinder, of large diameter, since a laminated sheet might split when being saturated. When a slow stock is used, each layer is naturally thin, and the faster the

speed of the machine the thinner is the layer. Consequently, when it is desired to get a thicker sheet or to increase the speed of production, several cylinders are used when the paper desired will permit of lamination.

Difficulty in maintaining uniform consistency of stock, and screening troubles, caused much operating uncertainty until more recent developments eliminated these variables. Careful attention to stock preparation and better regulation of stock flow have greatly improved stock formation. *Freeness* of stock should be carefully recorded, as it is difficult properly to felt a liner stock to a filler stock when the freeness varies too widely. Filler stocks, made from mixed waste paper, as in the manufacture of chipboard, are slower than liner stocks made from pulp. Ideal practice would be to process fibers to the same freeness for best formation, but to do so would reduce the tearing strength and folding strength of the liner. Fibers will felt well even though the freeness of the liner stock vary 125 c.c. from the filler stock, as recorded on a Canadian standard freeness tester.

It may here be noted that couch rolls C_1 to C_5, Fig. 110, are hung on levers, which are supported by pins 6 in the uprights 7; also, that the pressure of the couch rolls on the wet felt, between the couch rolls and the cylinder molds, can be controlled by the hand wheels and screws 8 and by the weights 9.

CYLINDER MACHINE DETAILS

347. Course of the Felts.—After leaving the last cylinder mold, Fig. 110, the wet felt goes to roll T, which is called a **strain roll,** since it must withstand the heavy pull caused by the change in direction of travel of the felt. On early machines, the felt turned around the last couch roll; but the strain sometimes bent the roll, and it has a bad effect on the formation of the paper. As the wet felt now starts on its journey through the machine, the paper is on its upper surface, and no longer hangs from its under side.

When the wet felt passes the first upright, it meets the upper felt, and the paper is gently squeezed between the two felts over roll 10, the squeezing action being positive, but gentle, because roll 10 is so placed that both felts pull down on it. The two felts, with the paper between them, now travel toward the press part; on the way, they pass between several pairs of rubber-covered

pressure rolls 11, and the water squeezed out is caught in troughs under the rolls. The upper roll of the first pair is rather light, and the upper rolls of the succeeding pairs gradually increase in size and weight.

The wet paper is now sufficiently compacted between the two felts to enable it to stand a greater squeezing without being crushed. This additional squeezing begins at the first *baby-press rolls* 12, and the squeezing continually increases in severity as the felts pass through the six baby-press rolls shown in Fig. 110, each pair of which has a drip trough under it. Each pair of these rolls may be heavier than the pair that precedes it; or a part, say the first half of a set of rolls, may be light and the succeeding half correspondingly heavy. The upper roll of a pair is usually rubber covered, while the lower roll is brass cased; this arrangement facilitates the removal of water with less danger of crushing. It is an advantage to have as few sizes of rolls as possible, to permit their being interchanged, if desired. Each upper roll of a pair can be raised by the hand wheels and screws 13. The weights and levers on each upper baby-press roll are so placed that the pressure between the rolls can be made lighter or heavier, according to the will of the operator. Since the paper is easily crushed, the water must be gradually coaxed out by a series of pressure rolls, as here described. There is usually no difficulty in getting enough pressure at this stage—the danger is that the pressure may be so heavy as to crush the paper. Therefore, the operator can so arrange the weights and levers that he can reduce the pressure whenever he fears that the paper will not stand up under it. The danger of crushing begins when paper is about as heavy as post card: lighter papers do not readily crush.

It is quite common to drive some, but usually not all, of the baby (or *primary*) presses: this relieves the strain on the felts. The baby presses are driven by chains and sprocket wheels from cone-pulley shaft L, as indicated for the two rolls at the right.

348. Reversing the Felt Travel.—There is a trend toward the installation of cylinder machines with the vats running in a direction opposite to that shown in Fig. 110, *i.e.*, toward the press part. This is shown diagrammatically in Fig. 111, where V_1 to V_5 are the vats; E, an extractor roll; F_t, top felt; F_b, bottom felt; FP, first press; S, suction felt roll; B, the sheet of board.

In the operation of this type of machine, the top liner, which is put on last and is the best stock, becomes the bottom of the sheet, the sheet being picked up on the top felt, the bottom felt being comparatively short. This arrangement can easily be duplicated on the standard machine by using a short top felt with an overhead whipper box.

349. Course of the Felts (Continued).—By the time the two felts have carried the paper through the last baby-press rolls, Fig. 110, it is sufficiently strong to be carried into the nip of a pair of press rolls X, which are in every way similar in design to the press rolls in the press part of a Fourdrinier machine. The *bottom*, or *wet, felt* carries the paper through the first press in exactly the

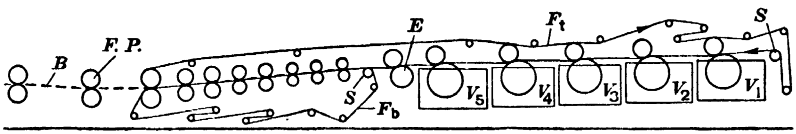


FIG. 111.

same manner as was described in the discussion of the press part of the Fourdrinier machine. The *upper felt E* leaves the paper and passes upward over the upper roll of the last pair of baby presses. On some machines, the felt continues to the first 'main' press, and then turns. Where the two felts pass through the first main press, it is an advantage to gear together the upper and lower rolls of this press. The upper felt is now carried overhead, on the framework supported by the uprights 7, to the wet end.

However, there is some difficulty in maintaining a pair of gears in correct relation to the diameters of the press rolls, since the top roll, usually covered, changes its diameter as it wears. A friction device and, later, differential gears were developed to overcome this change in roll diameters, but these were only partially successful. The newest device is a *controlled* drive, which enables the operator to obtain at will a slight differential in the surface speed of the two rolls.

In place of the flat suction box, there has recently been developed a small, light suction roll, mounted in antifriction bearings, which is turned by the felt and is supplied with vacuum in the usual way: this cleans and dries the felt sufficiently without the wear that is inescapable with a flat suction box. This device

increases felt life and improves the quality of the paperboard that may be made with it: it is applicable to both top and bottom felts.

Following this returning upper felt, 14, Fig. 110, is a hand felt guide, and 15 is a foot board, to permit the machine tender to cross the machine and clean the trough of the doctor *D* on roll 16. The side of the felt that is on top at this point is the side that has been next to the paper, and it therefore has pieces of fiber and filler sticking to it. This material leaves the felt as it passes under roll 16 and sticks to the smooth surface of the brass covering: the doctor *D* scrapes the roll clean. The felt then passes over roll 17, under roll 18 (similar to 16), and through the hand stretchers 19 and 20. The upper felt turns down over roll 21, and passes to roll 22, which can be moved by the hand lever shown, so the distance of the felt from the felt whipper 23 can be adjusted. Shower pipe 24 washes off the dirt that has been loosened by the whipper. Suction box 25 is a felt suction box; it removes dirt and water and smooths the nap of the felt. It is not always necessary to use an upper felt; some papers are sufficiently strong and firm to go through without this support.

Returning to the first press, where the lower wet felt is carrying the wet paper through the nip of the presses, follow the lower felt on its return to pick up the paper as it forms on the cylinder molds M_1 to M_5. The lower wet felt is so long that two hand felt stretchers 26 and 27 are used to tighten it. The felt whipper is shown at 29, the felt swinging guide roll at 28, the shower pipe at 30, and a felt suction box at 31. In addition to taking water from the felt after it has been wet, whipped, and squeezed, the suction box fulfills an important part, in that it brings back the *nap*, so the felt may be smooth and even, thus enabling it to pick up the sheet from the cylinders. The felt is now clean and dry, comparatively, and is ready to pick up paper once more from the cylinder molds.

A distinct difference exists between the functions of the press parts up to and including the first press and the presses that follow. Up to the first press, strict attention must be paid at every stage to the *safety* of the operation; that is, the water must be removed as quickly and cheaply as possible: and this must be done with special care, so the formation of the sheet will not be disturbed. During this part of the pressing, the sheet enters

the press containing about 6 or 7 pounds of water per pound of paper; but after leaving the first press, it should not contain over 2 to 2½ pounds of water per pound of paper. The removal of water to about 1½ pounds per pound of paper may then be done with less danger of injury.

350. The Presses.—The press part of the machine shown in Fig. 110 has four main presses; and the first wet felt has been followed with the paper through the first press *X*. The machine tender passes the paper from the first-press felt to the second-press felt at *K*. The first press *X* may be compared with the couch press of a Fourdrinier machine, and the passage of the paper at *K* may be considered as at the same stage in manufacture as when the paper passes from the wire and couchers on a Fourdrinier machine to the first press. Bearing this in mind, the reader will note, by studying Fig. 110, that the press part here shown consists of three presses, which are similar in design to the three presses described in connection with the press part of the Fourdrinier machine. As with the latter, the paper is reversed at the third press, in exactly the same manner, and the press housings, felt guides, stretchers, doctors, felt rolls, etc., are all the same.

351. Suction Presses.—**Suction primary presses** and **suction second presses** are in satisfactory use in a number of mills. These rolls are heavy, and they carry pressures of 150 lb. per linear inch. The bottom roll is rubber covered, and the top roll is of brass or granite. With a second press such as this, it is not usually possible for the **third press** to remove any water; it merely consolidates the sheet and adds to the smoothness of the bottom side, if the sheet is reversed. It is possible at the usual speeds for a press of this type to approach very closely to a 40-per cent stock content or to 1½ times as much water as bone-dry paper (sometimes referred to as 150 per cent saturation, see Art. **353**).

Regarding *suction pressing,* it is interesting to note that the water removal is accomplished almost entirely by the pressure exerted by the top roll, the vacuum assisting only in removing the water downward through the holes in the bottom, or suction, press roll. Also that greater results can be obtained at this point by making the suction press itself very strong and rigid to

stand a high pressure, rather than to depend on the results obtained by a high vacuum on the inside.

352. Crowning Press Rolls.—Crowning of press rolls is an important item. The total crown, top and bottom, between a pair of rolls is a function of the stiffness of the rolls. The object of crowning is to compensate for the sag of the rolls and establish uniform pressure across the rolls. All metal rolls, or metal and stone, or stone composition, can be definitely crowned to compensate for sag, even when heavily weighted. There is, of course, a correct crown for a definite weighting, but it is obvious that the crown cannot be changed with a change in weighting. So, when specifying the crown required, an average weighting is selected. Rubber-covered top-press rolls, being softer, also create difficulty in maintaining proper crown, but they definitely assist in prolonging felt life. These problems concerning press rolls emphasize the advantages of suction presses. Some of the newly developed methods of water removal during the first part of the pressing operation will now be described.

353. Roll Action.—It was formerly held that suction rolls were not suitable for use on cylinder machines. However, newer developments have changed this situation, and, since about 1930, their use has become standard for most grades of board. Difficulties were formerly encountered because the old suction rolls were not properly designed for the purpose, and the available pumps were not sufficiently powerful, or the operators did not recognize the necessity of applying sufficiently high vacuum and allow enough time for the application of vacuum.

Two slightly different methods have been developed for reducing the moisture content after the last couch to a point where suction pressing can be safely used; that is, in bringing the sheet from its condition at the last couch, which is between 12% and 15% stock content on a bone-dry basis, to a point of about 20% stock content, which indicates the point at which suction pressing can be safely undertaken at the speeds generally used. Instead of expressing the stock content in bone-dry fiber, the term **saturation** is commonly used. Thus, 20% b.d. stock content is equal to $\frac{100 - 20}{20} \times 100 = 400\%$ saturation; also 12% stock content equals 733%, say about 700% saturation; etc.

The action in operation of three kinds of press rolls is shown diagrammatically in Fig. 112. View (*a*) illustrates the conventional press or primary press, with solid-faced roll of any material, such as stone, rubber, or brass, in which the two felts

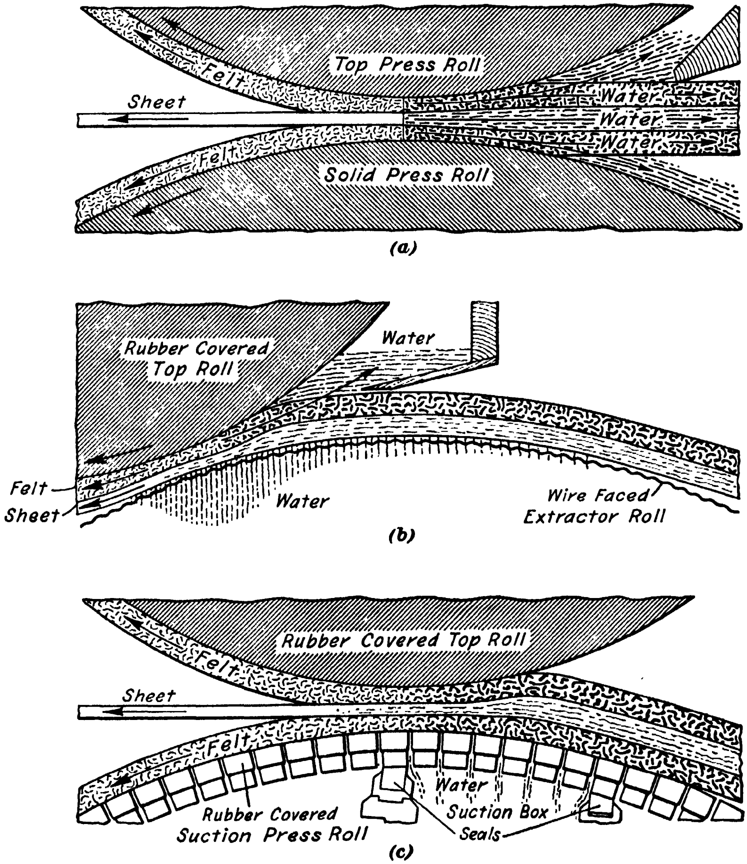


Fig. 112.

with the sheet between them pass between the rolls. The theoretical line of contact here is between the rolls where the greatest pressure is applied to the sheet and felts, and the tendency to supersaturation of both felts and sheets is just ahead of this line. It will be seen that both roll surfaces, both felts,

and the sheet are moving in the machine direction, while the water is obliged to move in the opposite direction for a considerable distance before it finally gets away from the sheet itself through the felts and flows around the ends of the bottom rolls or comes up through the top felt against the slice.

This supersaturation can be visualized as occurring at high pressure. If these rolls are carrying a nominal pressure, say 50 lb. per linear inch, this pressure is not carried by any considerable width of contact line between the rolls, certainly less than ½ in. in width, which makes the unit pressure at least 100 lb. per sq. in. On the later primaries and in the first press, the unit pressure at contact is at least two or three times this amount. Since this pressure is exerted on the sheet itself, it has a great tendency to wash the fine fibers of the sheet out of their proper position relative to one another, disrupting the formation, and causing 'checks' or 'crushing'; also causing the board to split in case it has not been properly plied (laminated) at the various molds. This checking may or may not be visible on the surface of the board; but, in either case, it interferes with the finish, more especially with the Mullen test and tear of the sheet, and with the rigidity.

View (*b*) shows a so-called *extractor press*, which is used directly after the last couch roll, as *E*, Fig. 111, before the second felt has come in contact with the sheet. In this case, the sheet itself at approximately 600 per cent saturation is pressed directly against the wire surface of the bottom extractor roll, where it can carry a line pressure of 50 to 60 lb. per linear inch. With a press of this kind, no tendency to crush or check is present, because the water is moved vertically downward through the wire face of the bottom roll, and neither visible nor invisible checking is produced. This type of press is sometimes used in duplicate, with a second installation just after the first, and can produce a sheet as dry as 400 per cent saturation.

View (*c*), Fig. 112, shows the suction-press roll, which also permits water removal downward into the holes of the suction roll, assisted, as shown in the illustration, by the pressing of the top roll and also by the vacuum applied to the interior of the roll. The vacuum is the principal item of interest here, since the sheet is still in its condition of approximately 600 per cent saturation, as received from the last couch roll.

354. Suction Drum Roll.—The suction drum roll *SD*, Fig. 113, is a large-diameter suction roll, with a very wide box inside, usually between 14 in. and 20 in. wide in the direction of machine travel. This arrangement is shown in detail in Fig. 114. A

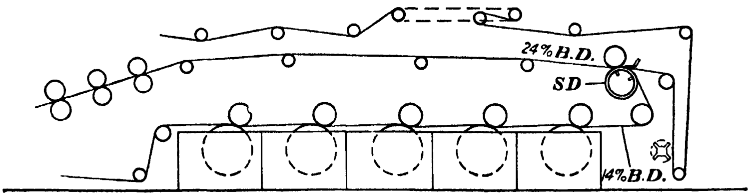


FIG. 113.

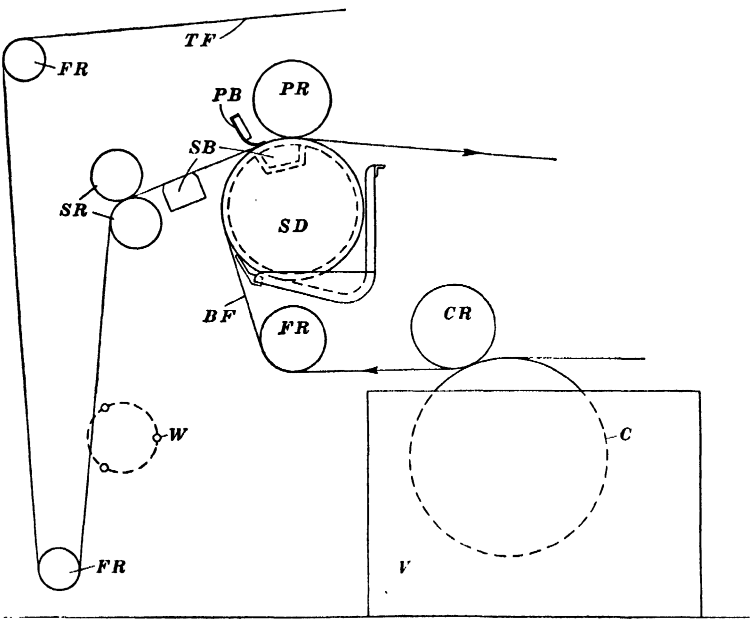


FIG. 114.—*V*, vat; *C*, cylinder mold; *CR*, couch roll; *FR*, felt rolls; *BF*, bottom felt; *TF*, top felt; *SD*, suction drum; *SB*, suction boxes; *PR*, press roll; *PB*, press board; *W*, felt washer. Note that Fig. 114 is the reverse of Fig. 113.

vacuum of at least 20 in. of mercury produces about 10 lb. per sq. in. of atmospheric pressure on top of the sheet; and this, though working through the felt itself, can remove considerable water and produce a sheet of about 400 per cent saturation, making it suitable to be carried next to the suction primary press.

355. Suction Drum Press.—Sometimes a very light top roll is applied to the suction drum roll just at the far edge of the wide suction box, where it can exert some pressure and produce a sheet up to nearly 300 per cent saturation under favorable conditions on comparatively lightweight free board.

356. Graduated Water Removal.—The term *duo-dehydration* is applied to water removal at this critical point in board making, and it indicates the dual nature of the requirements at this point, the first part being the removal of water up to about 400 per cent saturation. The second part of the term applies to further water removal up to a point of about 200 per cent saturation (33 per cent b.d. fiber content), which may be produced by a properly designed first press. This second part of duo-dehydration is effected by one or more suction primary presses and by a

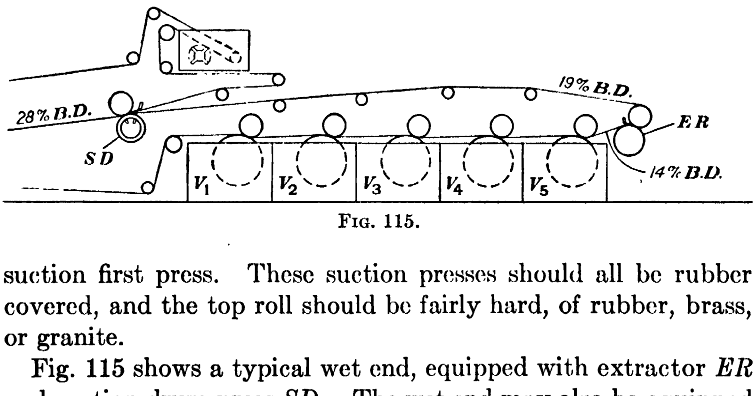


Fig. 115.

suction first press. These suction presses should all be rubber covered, and the top roll should be fairly hard, of rubber, brass, or granite.

Fig. 115 shows a typical wet end, equipped with extractor *ER* and suction drum press *SD*. The wet end may also be equipped with suction primaries and suction first press. The figures (in B.D. %) show the progressive dewatering of the sheet. Most, if not all, danger of board checking has been removed from a machine thus equipped, and this most critical part of the pressing job may thus be done safely on practically any grade or weight of stock, and at much greater speeds than have been possible with the old multiple primary presses and solid-faced first-press rolls.

Fig. 116 shows the wet end of a modern board machine, with forward-running pickup felt *F*, suction felt roll *S*, 6 vats with cylinder molds and couch rolls, 3 extractor rolls *E*, short bottom felt (or wire) *B*, rubber-covered suction primary and first presses P_1 and P_2. The board passes at *T* to the second-press felt.

357. The majority of board mills use three main presses instead of four, as shown in Fig. 110. The grade of board to be made must be taken into consideration, as there are two ways of running the first press: (*a*) to run the top first-press roll bare, as shown in Fig. 110; (*b*) to run it with felt around both top and bottom rolls. In the first case, the top felt is started back toward the whipper after it has gone through the last baby rolls, next to the first press.

When running on testboard, strength is more important than finish; in this case, it is best to use the second of the above methods, in order to get the sheet well pressed and as dry as possible before entering the second press. The dryer the sheet is at this point the less it will stretch in going through the second and third presses; and the less the stretch the less the formation of

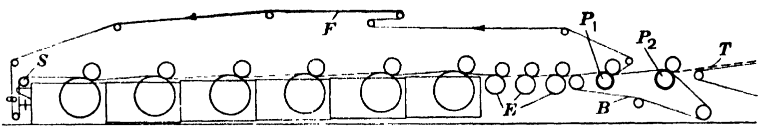


FIG. 116.

the sheet is disturbed and the greater the effect of the strong stock that is retained.

The first of the above methods gives a higher finish; but the sheet must be run slower because of the liability of sticking to the bare roll and of crushing. It is possible, however, to obtain good finish by use of the second method. In general, to get good production, the rolls and suction boxes up to and including the first press are relied on for water removal; the remaining presses consolidate the sheet and impart finish on both sides. The use of four presses is especially advisable when double-lined board is made, as this allows the use of heavier felts, which permit the same amount of water removal, with less tendency to felt mark.

The squeeze rolls 11, Fig. 110, are frequently neglected by machine tenders: but to get the most out of a machine, they should be kept true, easy running, and correctly weighted for the thickness of sheet run. The slices in front of couch, squeeze, and baby rolls must be set as close to the nip as possible; they must be rigid, and must not be bowed across the felt. If they do not press evenly on the felt all the way across, too much water will be let through it in the center; in the case of baby rolls, this

will cause sticking to the felt or first press. Light brass-tube rolls, revolving on the felt, have been successfully used for slices, which have for their object the removal to the ends of the rolls of the water pressed out, and the keeping of the felt from soaking up water back of the slices.

Generally, the printing surface of board is made on the last, or last two, rolls. After the reverse in direction of the bottom felt around the drum roll 9, this liner will be on top of the sheet; hence, the term *top liner*.

358. The Dryers.—The dryer nest of the cylinder machine differs widely from that of the Fourdrinier, because, first, this is a board machine, and the paper is thick (heavy), being probably as thick as a post card, or even heavier. Usually, there are no dryer felts or felt rolls, though some machines have a lower felt. The paper passes over dryer D_1, Fig. 110, under dryer D_2, over dryer D_3, and under dryer D_4. From the fourth dryer, it is passed up and over dryer D_5, then under dryer D_6, and over dryer D_7, from which it passes down and under dryer D_8. At this point, the drawing is broken in order to shorten it; but the part thus omitted is similar in all respects to the dryers just mentioned. The calender end of the dryers is indicated by dryers D_{54} to D_{60}. *Pl* is a platform, extending the length of the dryers, *CS* is a countershaft, *BG* a bevel gear, and *LS* the main shaft. The course of the paper from this point to the calenders is easily followed. There are usually three decks of dryers, and there may be four, five, or even six decks. Fig. 117 shows forty dryers arranged in four vertical stacks; the saving in floor space is obvious. The dryer gears in each stack intermesh; they are driven by pinions *G*. The paper from the last press is threaded through the dryers in the direction shown by the arrows. Ladders, which may be made of pipe, enable the operators to pass the paper over the dryers. This arrangement is applicable to relatively heavy papers or boards, where no felt is required. Second, owing to the thickness of the paper and the consequent shutting out of the air from contact with the center of the sheet, the dryer nest of a board (cylinder) machine must 'cook' the moisture out of the paper. The percentage of moisture in board is usually about 62 per cent entering the dryers, although some mills run as low as 58 per cent. The steam pressure in the dryers

of a board machine is generally higher than in the dryers of a Fourdrinier machine, which accounts for the higher production per foot of dryer surface. It is to be noted, however, that high pressures introduce possible dangers and are sources of troubles, not the least of which may be injury to the product.

Separation of the various plies on the dryers called 'blowing' is frequently due to high steam pressure in the first section of dryers. The sheet of board must first be raised to vaporizing temperature through to the center before moisture vapors are withdrawn from the surface. This will prevent what is commonly called 'case hardening,' with its attendant retardation of drying rate.

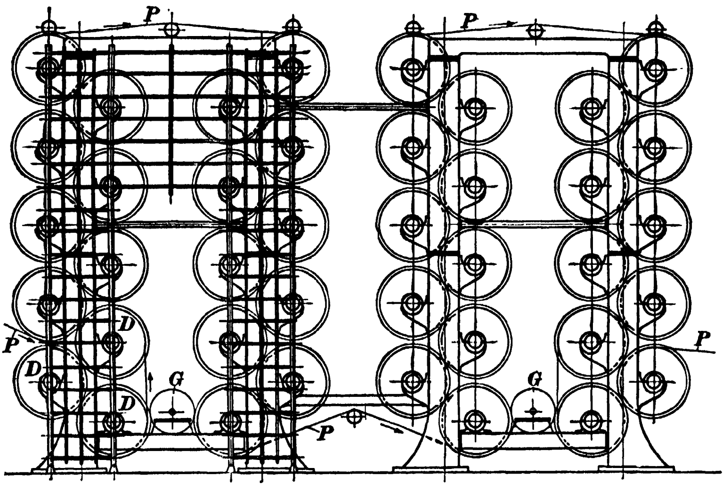


Fig. 117.

Vertical dryers are in successful operation on the manufacture of straw wrapping papers and on some cover papers. They can be run without dryer felts for such papers.

359. Dryer Details.—Where space permits, two-decked dryers are preferred, because of ease in passing the sheet. They are more easily cleared after a break, with less lost time, and their construction allows quick escape of moist air. The vertical stack arrangement is generally used when it is desired to increase production in limited space. Three- and four-deck dryers are in general use. Today's production demand, however, practically precludes the use of two-deck dryer systems, because of the space that the necessary number of dryers would require.

Usually, the dryers are the most neglected part of a board machine. The siphon pipes should be gone over once a month. The wet-end dryers should be kept clean of dirt and fiber by scraping with a sandpaper or wire-screen saddle; also, by use of good doctors. The framework, gearing, and dryer ends should be washed off with kerosene at least twice a year and carefully examined; this will bring to light many things that can be repaired before serious damage occurs. The line and witness marks should be examined, to make sure that no part of the machinery has gotten out of line.

The use of special drainage systems and of vapor-absorption systems has greatly improved dryer efficiency. In general, these systems have passed through the development stage and are fairly efficient and foolproof. The best drainage system is that which combines the greatest simplicity with a good efficiency.

While the amount of coal used depends on the grade and finish of the product, there are board mills using less than 1000 pounds of coal per ton of board. A typical figure for chipboard is 1800 pounds, and for test liners, 2200 pounds. Some board and saturating-felt mills are using 2 pounds of steam per pound of dried product.

360. Care and Operation.—The manner of removing the condensed water and renewing the steam supply is the same as for a dryer nest of a Fourdrinier machine. All that was stated in regard to dippers, siphons, steam joints, steam circulation, etc., in connection with the dryer part of the Fourdrinier machine applies equally to this part of the cylinder board machine. However, it is well to keep in mind the fact that cast-iron cylinders are not overly strong, and that the steam pressures carried in the cylinders of a board machine are often 40 pounds per square inch, gauge, or higher. The cylinders should be tested, therefore, before they are installed; but if this be not done, and the dryers have been in use for some time, they may then be considered to have been tested in practice.

Examine the cylinders periodically for signs of cracks; see that the springs on the bolts that attach together the ball-and-socket parts of the steam joints are in good condition and that they are not coil on coil. The spring-closing type of steam joint is really a safety valve, and springs may be ordered in accordance with

the pressure desired in the dryers; the steam joint will 'blow,' like the safety valve of a steam boiler, when the pressure within the dryer exceeds the limit permitted by the springs. Observance of this precaution may save life and property.

On either side of the dryers is a platform *N*, Fig. 110, for operating the top dryers. Power is applied to the dryers through intake shafts 37. The bevel gears 38 partly reduce the speed from the line shaft; this speed is further reduced by the pinion 39 on shaft 37, which meshes with the dryer gear. On the following sections of the machine, the proper speed reduction is obtained through gears 40 between the cone pulleys and the bevel-gear pinions.

361. Calenders and Winders.—Where highly finished board (Nos. 3 and 4 finishes) is to be made, as for folding boxes, three calender stacks are necessary. The first two are equipped with water boxes (from which calender colors are also applied); the third stack is dry, but usually has two hollow, steam-heated rolls near the top. For Nos. 1 and 2 finishes, one or two stacks suffice. Two stacks are shown, at 32 and 33, in Fig. 110.

Steam showers are sometimes used in place of water boxes, to give medium finish, usually in conjunction with sweat dryers. Spreader rolls or rods are used to prevent wrinkles in the sheet entering the top rolls, and calender doctors, preferably of the flexible type, are necessary.

The two-drum upright reel 34, Fig. 110, has a large core for the rolls of board, because of the great thickness of the sheet and the difficulty of bending it without cracking. Three-drum upright reels are also used when the rolls are small. All conditions as to design and care are the same here as in the case of the calenders and reels of the Fourdrinier machine.

The equipment for the slitting, cutting, and rewinding (in rolls) varies with the kind of boards being made. Modern practice is to slit the board from the reel by means of *duplex* or *instant-change slitters*. After being slit, the board then goes to a duplex or triplex cutter, if it is required in sheets, or to a two- or four-drum winder, if rolls are wanted. The duplex slitter is a separate unit, provided with two sets of slitters. The idle set is spaced for a new size while the machine is running, and at the proper time, it may be swung into place by a hand wheel without breaking down the sheet. The duplex cutter produces two differ-

ent lengths of sheets, and the triplex cutter produces three. The sheets are carried by a traveling apron, made of tapes, to the drop box, where the different sizes drop into segregated piles. If the sheets are to be finished (packed) at the machine, they are then weighed, jogged, and tied into bundles. If finishing is done in the finishing room, or if trimming is necessary, they are simply jogged and piled.

The differential winder and the two- or three-shaft upright winder are falling into disuse, because of the demand for better rolls and because of greater production requirements. A drum reel, similar to the type used in newsprint mills, is being introduced in board mills; it is said to be giving good satisfaction.

Cutters are more fully described in Part 4 of this Section, to which reference should be made.

362. Construction of Molds.—For box-board filler, cylinder covers of 40- and 50-mesh wire are used; for liners, 50- or 60-mesh wire is used, depending on the quality of board made. Because of the cumulative effect of the couch rolls, the sheet widens out slightly in passing from the first mold to the drum roll. For this reason, the width of open wire between deckles is increased in width from mold to mold; but as between the deckle width of the last mold and trimmed sheet at the cutter, the extra width is needed to allow for shrinkage and trim. If deckle spacing were not thus increased, the sheet would be pressed onto the deckle webbing, causing drop-offs (sheets leaving the felt).

Water deckles are in successful use in some mills; they are convenient where deckling-in (narrowing the sheet) is frequent, besides saving in shaving at the slitters. Molds as large as 72 inches in diameter are now in use; these have a greater drainage area, with consequent larger production.

363. Construction of Vats.—A vat with the cylinder mold removed is shown in Fig. 118. The stock from the headbox enters at the bottom of the vat at *S*, and the arrows show the direction of flow into the vat itself, past the baffles. This arrangement of partitions and baffles is similar in design and purpose to the corresponding arrangement in the flow-box of a Fourdrinier machine; it controls the inequalities of flow of the supply of stock. At *A*, it is quite usual to arrange for limiting

the supply to the cylinder by placing strips of boards in slots, thus raising the height of the dam over which the stock must flow; such an arrangement enables the machine tender to correct for quantity of flow without readjusting his supply of water or stock to the regulating box or screens. The journals of the cylinder mold rest in bearings at B; these bearings are preferably ball bearings, in order to reduce the strain on the felt, which acts like a belt to drive the mold. A passage E, cast on the head of the vat, is open inside the flange, where the cylinder mold and vat join; the white water that flows through the wire mesh can flow out through this passage, which is piped to the suction of the white-water pumps, W_1 to W_5, Fig. 110.

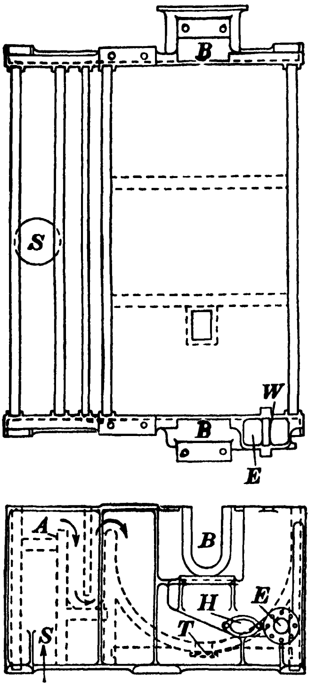


FIG. 118.

The plan view, Fig. 118, shows that the passage E from the interior of the vat to the suction of the white-water pump can be made easy or hard by so placing blocks of wood W that the white water flows over the top of these blocks on its way to the pump; this arrangement gives the machine tender another means of controlling the thickness of the stock on the mold, without interfering with the circulation of the stock or the speed of the machine. The height of the dam W determines the level of the stock inside the cylinder, and with it, the difference in level, or head, inside and outside the cylinder. H is a hand hole for cleaning out the inside part of the channels E, and T is a washout connection for the vat.

A typical assembly of vat and cylinder mold is shown in Fig. 119; this is a counterflow arrangement.

The smaller the clearance between the wire and the curved vat surface, called the *vat circle*, the better and more compact the formation but the slower the drying and the production. From 3 to 4 inches is commonly used in folding box-board

machines; but 6 to 7 inches is used on freer stocks, like chipboard and wallboard, when production is the object.

The direction of stock flow in the vat, compared with the direction of mold rotation, also markedly influences formation. When these are the same, the formation is more compact and with more grain. This method is used in electrical insulating board and tag manufacture, where close, strong formation is essential. Where they (stock and mold) move in opposite directions, as is usually the case in folding and setup board mills, the sheet is more open, and the fibers are distributed, to a considerable degree, in all directions. The molds, dams, and making boards (over which the stock flows into the vat proper) must be absolutely level, or the sheet will be uneven in caliper, because of the uneven depth of stock flow. A slice, on the principle of a Fourdrinier slice, has recently been designed for board machines.

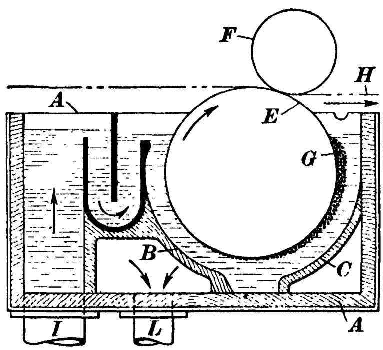


FIG. 119.—*A*, vat; *B*, back vat circle; *C*, front vat circle; *E*, cylinder mold; *F*, couch roll; *G*, fibers depositing on cylinder; *H*, felt and sheet; *I*, stock intake; *L*, white-water outlet.

In modern vats, especially on wide machines, the white-water is drawn out of the inside of the mold from both ends, as this contributes to more even caliper. A shower, placed on the descending side of the mold, cleans the wire. Sometimes, foam showers are used on the stock on the making boards. Modern vats also have quick-dumping valves, so the whole vat may be quickly dumped in the event of drop-offs.

364. Recent Designs.—A typical arrangement of a **uniflow vat** is shown in Fig. 120, the essential features of which include larger clearances between the cylinder mold and the inside of the vat, so as to allow the stock to run at lower consistency, with its attendent improvement in formation. Stock and water is overflowed from the back side, thus preventing thickening action of the stock on the uptake side. This overflow of stock is returned to the mixing box, or to the screen, as the case may be.

A recent development in vat designs is represented by the **cross-flow vat.** Since a cylinder sheet commonly has more decidedly directional formation than the Fourdrinier, there has been continual demand on some grades of paper or board with the density of formation obtained on a cylinder machine and the more nearly equal strength characteristics in cross and machine directions obtained on a Fourdrinier machine. The result has been the development of the cross-flow vat, in which the stock flows across the face of the cylinder at two points, front and back side. There is a stock inlet at the front side of the vat, with

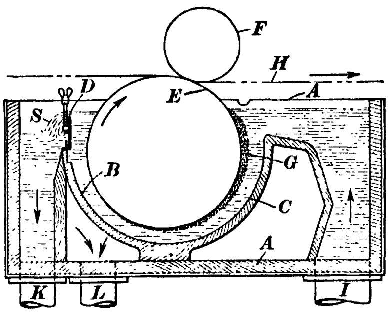


FIG. 120.—*A*, vat; *B*, back vat circle; *C*, front vat circle; *D*, overflow dam; *E*, cylinder mold; *F*, couch roll; *G*, fibers depositing on cylinder; *H*, felt and sheet; *I*, stock inlet; *K*, stock overflow; *L*, white-water outlet; *S*, stock overflowing and recirculating.

corresponding overflow at the back side. Another stock inlet is diagonally opposite, on the back side of the vat, with its stock overflow at the front side. Stock is thus fed from a main stock pipe to both sides of the cylinder mold. There is a white-water overflow on both front and rear sides of the vat.

The use of a *flow-evener* may improve formation. One type consists of a row of blades mounted fairly close together on a bar extending across the vat, in the entering stock stream. One edge of the blades conforms to the curvature of the cylinder. The whole unit is caused to oscillate and thus to keep the fibers in a state of uniform agitation.

365. Preventing Leakage into Cylinders.—There are patented methods for preventing stock from leaking into the cylinders where the ends of cylinder meet the sides of the vat. A flat rib is cast on the inside of sides of the vat, forming a circle, which corresponds in diameter with the end of the mold, and a lip left

on the mold comes to within about $\frac{1}{8}$ inch of the circular rib. A common way of preventing leakage is to pass a piece of dryer felt over the lip and rib, drawing the ends of the felt together above the vat with a turn buckle. Since this piece of felt will act like a brake, the ends must not be drawn too tight.

Another good way to make a suitable deckle strap is to wrap about three thicknesses of old press felt on a piece of lightweight rubber belting, of a width that will just cover the lip on the mold and the rib of this vat; this may be attached as described above by any suitable means. A strap of this type makes a tight joint without being drawn excessively tight.

Felt collars rot quickly, especially in hot weather; they must be examined weekly, and changed if necessary. Leaky collars will result in serious stock losses, and unless a save-all is used, this condition may continue for some time without being noticed.

366. Regulating Thickness of Paper.—The thickness of the paper made on a cylinder machine on any one cylinder mold depends on several conditions: the kind of stock; the amount of water in the stock; the speed of turning of the mold; and the difference between the level of the stock outside the mold and the level of the white water inside the mold. This matter is more fully discussed in Section 6, Vol. III.

Stock that will lose its water rapidly through the mold is called **fast** or **free.** First in the order of freeness are the sulphite and sulphate pulps; next comes soda pulp, and then groundwood; the slowest stock is hot groundwood. Stock from old papers is generally *slow*.

As indicated in Art. **371,** formation takes place on the two parts of the wire (on opposite sides) that are in contact with the stock on the outside and are not touched by the white water on the inside (that is, the parts of the cylinder between the liquid levels inside and outside), except by that water flowing through the meshes. The formation is caused by the static head, or pressure, of the water outside; and if this level be made equal to that inside, formation will cease. This may also occur if there is excessive foaming.

In starting a cylinder machine, the machine tender equalizes his 'suctions'—or level of white water inside the mold—by opening the valves on the discharge lines of the white-water

pumps W_1 to W_5, Fig. 110, the same amount. With the wire showers turned on, the sheet is then brought to weight at the machine regulating box. Equal volumes of stock must flow to each vat; otherwise, one mold will receive more than its share of stock, and this will cause blowing at the following mold, since the water must be pressed upward through the sheet and felt during couching. If the stock is too free, the webs on the cylinder molds will pick when running a thin sheet, and cause breaks. It is therefore necessary to have the stock slower, the thinner the sheet, in order to get a close formation; for the same reason, it is preferable to form it on fewer molds than for thick board.

367. Machines for Leather Boards, etc.—Single-cylinder machines, without dryers, are used for making leather board, trunk board, etc.; they are similar in principle and operation to the wet machines described in Section 6, Vol. III. The board may be dried by hanging in a hot-air chamber or by spreading in the sun.

368. Suction Roll.—The use of a suction roll for a cylinder mold is a recent development of the cylinder machine. The principle of the suction roll has been previously explained. Some rolls are turned by the felt, while others require a separate drive, even with ball bearings. The thickness of the sheet is regulated by the amount of suction, other conditions being the same, instead of by the difference in levels between the stock and white water, as in ordinary cases. Suction rolls have not yet been a success on multicylinder machines.

369. Other Rolls.—The couch roll *C*, Fig. 110, consists of wooden lagging, fitted on spiders keyed to a central shaft; the outside of the lagging is then turned true and is ready to receive the felt covering. The felt rolls, stretch rolls, guide rolls, whippers, showers, etc., are all practically the same as for the Fourdrinier machine, as previously described.

Soft-rubber couch rolls, of lighter weight, are displacing the felt-covered, or Hoffman, couches. To insure a perfect fit when a new wire is put on, a new felt couch should be installed. This is unnecessary with rubber, which does not develop hard spots, and which retains the same plasticity for a long time.

370. Press Section.—Water removal by means of suction drum rolls or suction primary presses and suction main presses

has been widely used in recent years. Main-press sections were formerly arranged with top press roll of chilled iron and a gumwood bottom roll. Today, however, the first press may carry an iron bottom roll with a brass top roll, or even hard rubber. A few stonite press rolls are in use. Bearings may be phosphor bronze or antifriction, each self-alining. Pressure may be applied to the journals of the top press rolls by means of powerful springs, which are compressed by the action of heavy screws operated by a ratchet lever or hand wheel, or else by the lever and weights described in connection with the Fourdrinier machine. One end of the bottom press roll is fitted with a bevel gear G_1, Fig. 110, which connects by a shaft on the bevel pinion with a spur gear G_2; the latter meshes with a spur pinion G_3, which is keyed to a countershaft. The countershaft carries a cone pulley, which is belted to a cone pulley on the variable-speed line shaft. On some machines, the various sections are driven by individual motors: such synchronized drives are described in Part 6 of this Section.

371. Production Speed.—The speed of production, or the paper speed per minute, of a cylinder machine is evidently the same as the surface speed of the cylinders, *after allowing for the stretch of the paper through the machine.* The thickness, or weight, of the paper to be made can be increased by speeding up the removal of the white water from the inside of the cylinder mold, so as to increase the suction surface of the wire mesh. This suction surface is that part of the wire mesh which is in contact with stock on the outside and is not touched by water on the inside, except by what water is flowing through the mesh. This surface is evidently at its maximum when the white water inside the cylinder mold is at its lowest level. The thickness of the forming fiber on the wire mesh of the cylinder mold (and, therefore, the weight of the paper) can also be increased by reducing the amount of water in the stock from the headbox. Newsprint paper has been made on a cylinder machine at 500 feet per minute.

372. Amount of Water Used.—The amount of water used in a cylinder machine depends upon the kind of stock, the speed of the machine, and the grade of paper or board being made. For a machine making 24 tons of paper per day, the amount of water added at the regulating box to bring the consistency of the

stock to $\frac{1}{2}$% will depend upon the consistency of the stuff entering the regulating box. Thus, if the consistency of the stuff were 4%, the added water would be 4200[1] tons; and, if the consistency were 2%, the added water would be 3600 tons. Since the board as it goes to the dryers contains about $33\frac{1}{3}$% dry fiber, it will carry less than 100 tons of water, which means that about 4800 − 100 = 4700 tons of water are removed by the cylinders and presses. A large amount of the water for regulating the consistency may be supplied by the white water. Any white water not so used is passed to a pulp saver, and the clear water from this may be used for showers, for filling beaters, etc.

373. Strength of Paper Made on Cylinder Machine.—The cylinder machine is not usually provided with a shake, in which respect it differs from the Fourdrinier machine. As a consequence, paper made on a cylinder machine has a higher tensile strength in the direction of the machine run than it has in the opposite direction, *i.e.*, across the machine; and the difference of the strengths in the two directions is much greater than is the case with paper made on a Fourdrinier machine. Paper made on a cylinder machine is usually heavier than that made on a Fourdrinier machine; but when a light paper is made, it is cheap in quality, and the matter of strength by test is unimportant. Many attempts have been made to felt the fibers on a cylinder machine, one device being to use agitator blades in the vats, thereby continually stirring the contents; sometimes the cylinders are shaken. In the case of a certain patented machine, a suction cylinder mold is used; a Fourdrinier wire encircles this, receives the paper, carries it over one or more suction boxes, and conveys the paper over a couch roll, where it is transferred to a felt.

374. Expense of Operation.—As a rule, the cylinder machine can be operated at less expense than the Fourdrinier machine; it is well adapted to the manufacture of papers that do not need to have the fibers so thoroughly felted crosswise as papers that are made on the Fourdrinier machine. These papers derive

[1] This amount is determined as follows: $\frac{1}{2}$% = 0.005; 24 tons ÷ 0.005 = 4800 tons of stock per day having a consistency of $\frac{1}{2}$%. 4800 − 24 = 4776 tons of water. For 4% stock, the weight is 24 tons ÷ 0.04 = 600 tons of which 600 − 24 = 576 tons is water. The weight of water that must be added to this last to make the consistency of the stock $\frac{1}{2}$% is, therefore 4776 − 576 = 4200 tons. A similar calculation made for stuff of 2% consistency will show that the amount of water to be added is 3600 tons.

their strength from their thickness and through the use of tough and coarse fibrous raw materials. Among the latter may be mentioned wood pulp, hemp, old rope, gunny bagging, hemp and jute butts, and certain straws and grasses, such as esparto. Old newspapers are also employed in the stuff used for the lighter grades of boards. Mixed waste paper and used corrugated boxes are also largely used in the manufacture of board.

The consumption of deckles, jackets, the long Fourdrinier wire, and of dryer felt is avoided in the cylinder machine, together with a large part of the wear and tear of the Fourdrinier mechanism in general. The simplicity of the cylinder-machine mechanism, and the speed at which it is run, are the causes of its great longevity. The most expensive item is the felt cost. The felts are very long; and the strains induced by the turning of the molds and rolls, and the friction and pressure of the presses, cause rather rapid wear.

375. Scope of Cylinder Machine.—The cylinder machine is particularly adapted to the making of tissues, as well as the various kinds of boards and bristols, the latter being used for index cards, etc., and by artists. Since the stuff employed for making boards is slow, parting with its moisture slowly, the problem of making a thick board is solved on the cylinder machine by forming a thin sheet on each of the cylinders and then joining these into a single sheet by the presses, thus producing an excellent laminated board.

The scope of the cylinder machine in the matter of utilizing the variously differing raw materials is very great; and the expense of operation can often be offset by using by-products of other manufacturing industries. The income to be derived from the converting of by-products into paper, to be used again in the main department of the same plant that discarded them, or else to be sold elsewhere, is almost too obvious to make it necessary to suggest that manufacturers having any waste fibrous material will do well to consider saving it by installing cylinder paper machines.

THE DIFFERENTIAL WINDER

376. Purpose of Differential Winder.—The winder that is generally used on board machines, and on many old paper machines, is called a **differential winder**; it is so called because of

the differential gear that permits two shafts to run at relatively different speeds. If the rolls of paper were all of the same size, the shafts could all turn at the same speed. Sometimes, however, it is necessary to remove defective paper or board from only one roll. This roll is then smaller in diameter than the other rolls, and the shaft on which the smaller roll is winding must then turn more rapidly than the others, in order to keep the surface speed and the tension of the paper the same as on the other rolls. It is to be noted that the paper being wound is coming from the reel in one single sheet.

The differential gear of a two-shaft winder is shown in Fig. 121; an additional differential gear must be used for each extra shaft, and the four-shaft winder, which is often used, will thus have three differential gears, which will permit of adjustments of speeds to all four shafts.

377. Description of Differential Winder.—Referring now to Fig. 121, which shows in diagrammatic form the shaft winder and its differential gear, shaft A is the driven shaft, the power being applied to the driving pulley P, which is keyed to shaft A. The epicyclic gear D (an **epicyclic gear** is one that *rolls* on the *outside* of another gear) can revolve on the journal on the end of arm N, which is keyed to the shaft A; hence, every time the shaft A revolves, gear D and its journal must make a complete revolution in a circle whose center is on the axis of shaft A, and the circular surface described by the axis of gear D will lie in a plane perpendicular to the axis of shaft A. If the lock pin L shown on gear D is *in*, and gear D is thus prevented from revolving on its own axis, which coincides with the axis of the journal on the end of arm N, then one revolution of shaft A will force the gears B and C, which mesh with gear D and fit loosely on shaft A, to revolve one revolution also; and they, in their turn, will revolve gears E and G, which are keyed or fastened to the hubs of gears B and C. Gears E and G drive gears F and H, respectively; these last two gears are keyed to shafts M and M', which have sliding clutches K at their ends, connecting them to shafts S and S' on which the paper is rolled. Gear D is sometimes balanced by a similar idle gear D' on the other end of the arm N; the purpose of this gear is to secure a balanced arrangement and an even *torque* (turning moment) at each end of the arm. When reading the following

explanation, attention should be paid only to gear *D*, since its duplicate in size *D'* has no effect on the working of the mechanism.

Now imagine that the lock pin *L* is *in;* this will prevent gear *D* from revolving on its journal. It is at once evident that, as shaft *A* revolves, it will carry the arm *N* around with it; and, since gear *D* is then rigidly attached to its journal, it simply acts like a solid bar connecting the two gears *B* and *C*. This condition

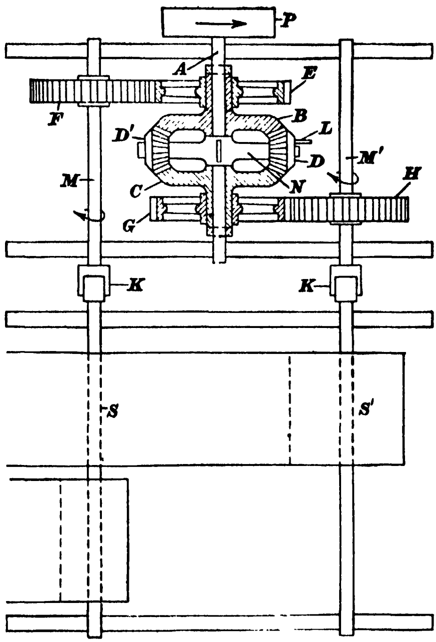


FIG. 121.

causes these two gears to revolve uniformly (and at the same rate) with shaft *A*, in the same manner exactly as though they were keyed directly to the shaft *A* and there were no arm *N* or gear *D* in the mechanism, as though the entire mechanism were one piece. In this case, the paper rolls on the two shafts *S* and *S'* of the winder will be constrained to run at exactly equal speeds.

Now consider what happens when it is desired to run the paper rolls at two speeds that differ widely in the number of revolutions per minute. To take an extreme case, suppose that

the paper roll running at the slower speed is not turning at all; with this thought in mind, refer to the illustration, Fig. 121, and see what is happening under these conditions. The driving shaft A is still running at the same speed as when both rolls S and S' turned at equal speeds, when the lock pin L prevented gear D from turning. The lock pin is not locking gear D now, and the paper roll on shaft S' is so large and heavy that gear H cannot be turned by the power supplied by gear G; in other words, gear G is now stationary. An examination of the differential gearing in actual motion will show that, under these conditions, gear C (which is keyed to gear G) is standing still, that gear B is running faster than shaft A, while gear D is turning rapidly on its journal on the end of arm N. Since gear C is stationary, a revolution of the arm N about the axis of shaft A will cause gear D to revolve about the axis of the journal on the end of arm N; and the number of turns of D for one revolution of N will be equal to the quotient obtained by dividing the number of teeth in C by the number of teeth in D. Since D meshes with B, it is evident that, if D turn, B must also turn. If pulley P turn in the direction indicated by the arrow, then, with gear C fixed (stationary), arm N and gear B will turn in the *same* direction as pulley P. Gear E, which is keyed to the hub of gear B, thus turns in the same direction as B, and it causes gear F to turn in the opposite direction, which is *opposite to the direction in which pulley P turns.* Evidently, then, when shafts S and S' both turn, they turn in the *same* direction.

To simplify matters, suppose that gears B, C, and D all have the same number of teeth. Then, with gear C stationary, one revolution of arm N will cause gear D to make one revolution on its axis; and since gear D meshes with gear B, one revolution of D will cause B to revolve once also. But the revolution of arm N also causes B to revolve once, as was seen above, when lock pin L was in. Consequently, with gear C stationary, one revolution of the arm N will impart $1 + 1 = 2$ revolutions to gear B, one being due to the arm N and the other to gear D. In other words, gear B will turn *twice* as fast as the shaft A and pulley P. But gear D on a winder is always smaller than gear B.

If, now, gear C be also turning (instead of being stationary) in the same direction as gear B, and with the same angular velocity as the arm N, it will entirely neutralize the turning of gear D

in its effect on gear B, and the number of revolutions per minute of gear B will then be the same as that of shaft A and pulley P. If the angular velocity of gear C be a little less than that of arm N, the revolutions per minute of B will be a little greater than the revolutions per minute of A and P. It is now evident that the greater the difference of revolutions per minute between arm N and gear C the greater will be the excess of the revolutions per minute of B over the revolutions per minute of shaft A, and this will be automatically taken care of by the differential gear. The final result is that the speed of pulley P is constant, while the speeds of the winder shafts S and S', relative to each other, are automatically adjusted to suit the working conditions. The size of gear D, or the number of teeth it contains, evidently has no effect whatever on the relative motions of gear B and shaft A.

The practical operation of the differential gear may, perhaps, be better understood if the reader will imagine himself as taking the place of gear D, when two rolls of paper of different diameters are being wound on shafts S and S'. Suppose he lie face down, with one hand pressing on gear B and the other hand pressing on gear C. Since the rolls have different diameters, the one having the smaller diameter will turn more easily than the other. Consequently, in order to keep the pressure constant and equal on the teeth of both gears B and C, he must press down on the gear that connects to the smaller roll, in order to increase its speed until the pressure on both gears is equal. This explains why gear D is forced to move around its center toward the point of least resistance, thus increasing the speed of the smaller roll until the *work* done on rolls S and S' is equal. The slightest difference of resistance to winding, which is proportional to the difference in diameters of the two paper rolls, will always cause the differential gear to act as just described. A small hand-operated model of a differential gear is described in Part 6 of this Section.

378. Shafts.—These are usually square; the paper is wound on wooden cores, with square holes, which are slipped on the shafts and held in place by collars with set screws. The screws should be countersunk into the collars, as a projecting set screw is a prolific source of accidents, owing to its catching in loose clothing.

379. Direct-Connected Cutter.—Frequently, the board made on a cylinder machine is too stiff to wind. In such cases, the

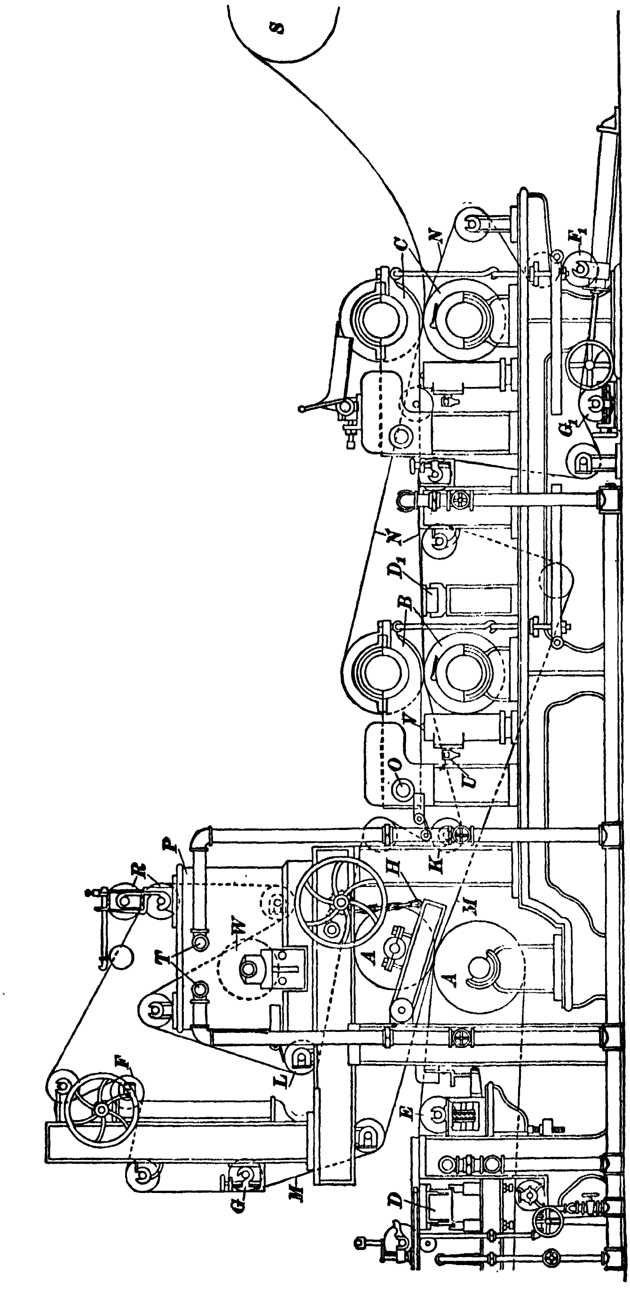


FIG. 122.

sheet may go from the dryers, through the calenders, through perhaps only one nip of a very heavy pair of rolls, then through a slitter, and be chopped off into sheets of the required length. Frequently, also, a duplex cutter is used, so as to cut different lengths on the several strips; an arrangement of this kind was shown and described in Vol. III, Section 6. Cutters are more fully described in Part 4, of this Section.

SPECIAL PAPER MACHINES

MACHINES FOR MAKING TISSUE PAPERS

380. Classification.—The Fourdrinier paper machine and the cylinder paper machine are the standard machines of the paper-making industry; but there are papers that cannot be made on either of these two standard machines, unless the design of the machine itself be greatly altered. A brief description of the most important changes in the design of standard machines in order to adapt them to the special requirements of the papermaker will now be given. These special designs of paper machines may be roughly divided into three different types, as follows:

I. Fourdrinier and cylinder paper machines for making tissue papers or papers too light in weight for the machine tender to pass from the wire to the wet felt.

II. M. G., or machine-glazed, papers, the design requiring the use of a dryer of large diameter.

III. Combinations of Fourdrinier and cylinder machines.

The machines of type I may be divided into two classes, namely:

a. Fourdrinier machines with tissue attachments.

b. Harper machines.

The machines of type II may also be divided into two classes:

a. Fourdrinier machines having a big dryer called a Yankee or Flying Dutchman; this type would include a Harper-Fourdrinier machine if it were provided with a Yankee dryer for making M. G. tissue paper.

b. Cylinder machines with a Yankee dryer.

The machines of type III, used for making double-faced paper, are combination Fourdrinier and cylinder machines, or they are Fourdrinier machines for heavy paper, having a wire on the top couch roll, *i.e.*, a double wire.

381. Fourdrinier Machine with Tissue Attachment.—A Fourdrinier machine with an Edwardes attachment for making tissue paper is shown in Fig. 122. The purpose of the **Edwardes attachment** is to simplify the operation of carrying lightweight paper from the wire to the dryers. The Edwardes method includes the use of a felt wash box P, where the felt is cleaned by a whipper W and washed by shower pipes T, which are installed in a box on top of the machine. Felt M, instead of being reversed at the couch roll and running directly through the nip of the first press, must run in the *same* direction as the couch roll and be reversed at the press. From the press rolls, felt M is guided by the felt rolls into the box P, where it is cleaned and washed by the felt whipper and showers; it is then pressed dry by the brass-covered squeeze rolls R. From the squeeze rolls, felt M returns over a felt roll, passes down and around the roll F on the vertical hand stretcher, over another felt roll, down to the hand guide roll G, thence under another felt roll, and back to the nip of the couch rolls A. As felt M passes, in a reverse direction, over suction box D_1 and through the nip of the first press, it loses the paper to felt N, which carries it over the top of the first-press roll and into the nip of the second press, in the direction in which the machine is running. As the paper is automatically passed through the nip of the second-press roll in the manner just described, it is picked off the felt N and is passed by the machine tender to the receiving dryer S. Felt N, returning from the second press, passes over and under the felt rolls, around the stretcher roll F_1, over the hand guide roll G_1, under a felt roll, over a guide roll, beneath a shower pipe, and so on, back in a reverse direction, to the nip of the first press, where it picks the paper off felt M. The chains H, operated by a hand wheel and ratchet, lift the upper couch roll clear of the wire. The press rolls are lifted by levers through the lifting bar V, O being the fulcrum, which is raised by ratchet levers U, operated by a gear.

Other forms of tissue-handling devices are all similar in principle, but they differ in the arrangement of rolls or in the lead of the felts, according to the ideas of the designers.

382. Other Devices.—A tissue attachment that illustrates the principle of several patented devices is shown in Fig. 123. The reader is again cautioned in regard to possible infringements of

patents. The man who invents and patents a device or process is entitled to a royalty for the product of his brain, and the law says that he shall have it.

The arrangement of the carrying felt M is shown in the diagrammatic sketch, Fig. 123; the felt picks up the paper from the wire and carries it through the nip of the press to the receiving dryer, against which it is pressed by roll Z and gear Y. The doctor J, held by spring K against dryer S, scrapes off any paper that may stick to the dryer.

The rolls used inside a felt, to press the felt and the paper it carries against a polished receiving roll, should be provided with

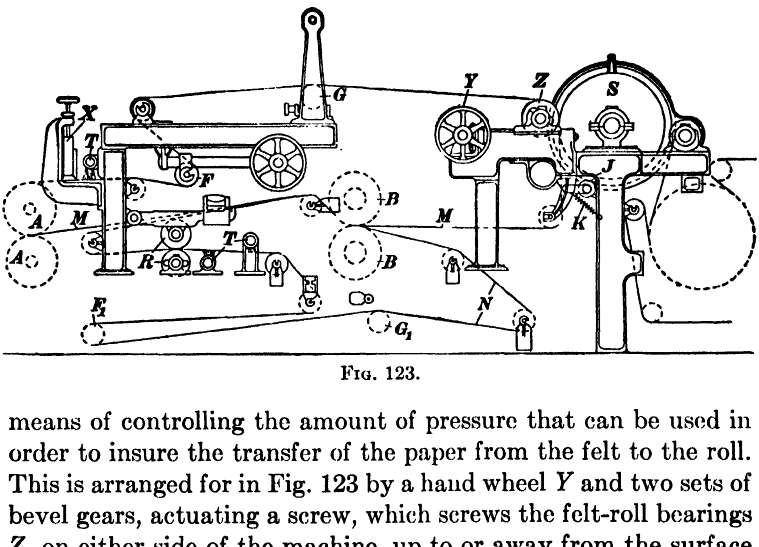


FIG. 123.

means of controlling the amount of pressure that can be used in order to insure the transfer of the paper from the felt to the roll. This is arranged for in Fig. 123 by a hand wheel Y and two sets of bevel gears, actuating a screw, which screws the felt-roll bearings Z, on either side of the machine, up to or away from the surface of the receiving dryer roll.

383. Harper Machine for Making Tissue Paper.—The Harper-Fourdrinier machine for making tissue paper is illustrated in Fig. 124; it is shown with one press and a receiving dryer. This machine has eight dryers in the nest, one three-roll calender stack, a two-drum upright reel, and a two-drum winder; since these parts are standard, they are not shown in the illustration. The flow-box I is between the Fourdrinier part and the first press; that is, the position of the Fourdrinier part is reversed, because this arrangement is more convenient for securing a long

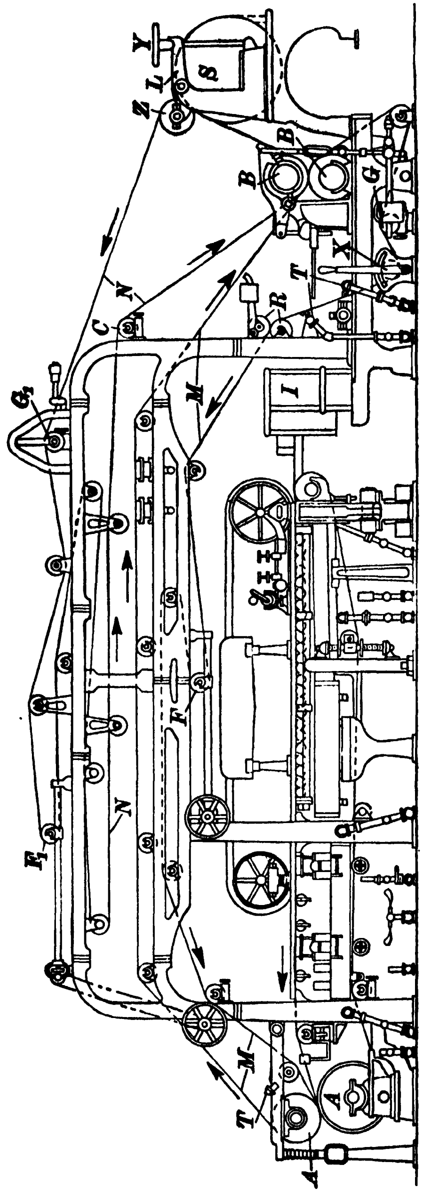


Fig. 124.

run of the necessary felts. This Fourdrinier part may be compared with that of Fig. 25, Part 1; the details are practically the same in both illustrations, but the wire here shown is shorter.

Following the run of the stock from the flow-box to the couch press, no dandy roll is found, because, in this case, the finish of the paper does not require it. The palms on the guide mechanism are clearly shown. When the couch rolls *A* are reached, a felt *M*, which acts like a couch-roll jacket, picks up the paper from the wire and carries it back over the Fourdrinier part and through the nip of the press rolls *B*. Felt *M* passes from the press-roll nip, down under a felt roll, over a guide roll *G*, and then under the hand-tightener roll *X*, which is adjusted by means of a lever. From roll *X*, the felt goes between showers *T*, past a felt whipper, through squeeze rolls *R*, around the stretcher roll *F*, over two more felt rolls, a hand guide roll, and from there back again over the Fourdrinier part to the upper couch roll.

Felt *M* has now delivered the paper from the couch rolls to the first-press felt; from here, just after passing through the nip of the press, it is picked off felt *M* by felt *N*, and is carried to the receiving dryer *S*. The polished surface of dryer *S* causes the paper to leave felt *N*, as it is pressed against the surface of the dryer by roll *Z*, which swings on the pivoted lever *L*. The pressure of roll *Z* against the dryer is adjusted by the hand wheel and screw *Y*, as shown. From this point, the travel of the paper is the same as through any standard type of paper machine. Felt *N* leaves the paper on the receiving dryer *S* and travels over the framework above the Fourdrinier part; it passes over the automatic felt guide G_1, the hand stretcher F_1, six felt rolls, and, lastly, over a hand-adjustable guide roll *C*; after passing *C*, the felt returns to the nip of the press roll, to pick off the paper from felt *M* and deliver it to the receiving dryer *S*.

With this arrangement of felts, the paper travels automatically from the couch rolls to the dryers without any handling by the machine tender, a decided advantage, because paper made on a Harper machine is generally too light to handle. The automatic transfer of paper all through a machine will be discussed later. All paper machines can be designed to transfer the paper automatically from end to end of its travel, and this should always be done on high-speed machines, if circumstances permit.

384. Probably the most important detail in the design of the Harper-Fourdrinier machine is the couch-roll housing, the lifting arrangement of which should be capable of very delicate adjustment, so as to permit of a gradual variation of the pressure between the two rolls. Since tissue paper is easily crushed at the couch press, the screws and counterweights on the lifting arm should be so adjusted that the rolls may touch without any pressure being exerted. All tissue attachments to a Fourdrinier machine are similar in general design to the types here described. For some papers, only four rolls may be required in the calender stacks, and less than eight dryers may suffice.

MACHINES FOR M. G. AND OTHER PAPERS

385. Yankee Machine.—M. G., or machine-glazed, papers are made on a Yankee machine. The **Yankee machine** (or, as it is sometimes called, the **Flying Dutchman**) may have a cylinder or a Fourdrinier wet part, and it may have any number of presses or auxiliary dryers of the usual type; but its characteristic feature is the large dryer, from 9 to 15 feet in diameter and made of such quality of cast iron or steel that a very high polish may be imparted to its outside cylindrical surface. If pressed with sufficient force against a heated, finely polished surface, any soft material, like paper, cotton goods, etc., will come away with a fine-glazed, smooth surface after drying, a reproduction of the polished hard surface against which it was pressed; the other side, however, will not be so smooth, unless both sides touch polished hard surfaces. The truth of this statement can be demonstrated by thoroughly wetting a handkerchief and carefully spreading it out on the smooth flat surface of a windowpane or the porcelain lining of a bathtub. When dry, the handkerchief will be found to be very smooth on the surface that touched the windowpane or the side of the bathtub.

If a satisfactory high-glazed finish is not obtained on the paper by hard pressing against the surface of the Yankee dryer, then the surface of the dryer is not sufficiently polished. If the paper contain too little moisture when it comes in contact with the dryer, it will not glaze well; but a satisfactory glaze may then be obtained by wetting the surface of the paper with a fine spray or with a steam jet. However, the sheet must not be too wet.

Papers are sometimes glazed in calendering; in such case, a glazed finish can be obtained on both sides of the sheet. If, for any reason, such as a desire to increase the output, the Yankee dryer is preceded by a dryer part of the usual type, the paper will arrive at the Yankee dryer in a condition too dry to glaze, and it must then be wetted properly by some sprinkling device before it touches the surface of the Yankee dryer. Usually, it is not necessary to have a felt on the big dryer of a Yankee machine, if it be used for glazing purposes only; but the capacity (speed) of the machine can be increased, and the dryer can be used for drying as well as glazing by using a dryer felt.

386. Carrying Tissue Automatically from Couch Roll.—Fig. 125 is a diagram showing the run of the clothing on a machine that

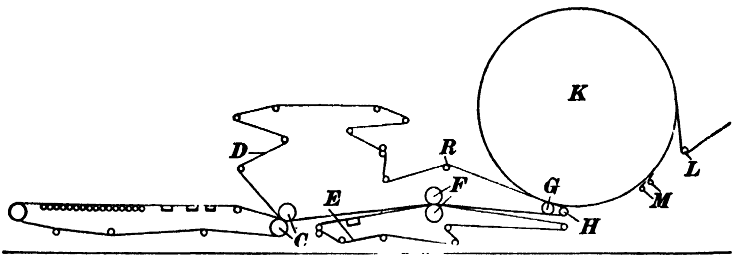


FIG. 125.

is designed to carry tissue paper automatically from the couch rolls *C*, through the presses, to the large (10 to 14 feet diameter) Yankee dryer *K*. The top felt *D* here carries the paper from the couch rolls *C* to the wet press *F*, where it meets the lower felt *E*. The paper can be passed over the tail roll *H*, which does not touch the dryer *K*, from the lower felt, if it be necessary; as a rule the top felt carries the paper right through. Roll *G* presses the paper against the polished surface of dryer *K*, to which the paper sticks. By the time the paper has reached roll *L*, it will have peeled from the big dryer or will readily pull off, and it can be passed under swing roll *L* and through a calender stack. Or, if desired, it may go directly to a reel, and from there to a slitter and winder.

The felts are provided with stretch, guide, and squeeze rolls, and the lower felt passes over a suction box. Roll *R* is adjustable, in order to vary the length of the arc of contact of the felt

D with the dryer; in some cases, the felt wraps more than half way around the dryer. The purpose of the two doctors shown at *M* is to peel the paper from the dryer in case of a break, thus preventing any winding around the dryer; they also keep the surface clean and polished. The surface, of course, must never be scratched.

The temperature of the dryer must be carefully controlled; it must be cool enough to take the paper from the felt, and it must be hot enough to dry the paper in about three-quarters of a revolution of the dryer. Some machines are built having a number of small dryers equipped with the usual felts and having a large Yankee dryer at the end, to give the M. G. finish; such an arrangement allows a higher speed on heavy papers. The wet felts may be so woven as to impress a special design on the moist paper while it is being pressed against the big dryer.

The diagrammatic sketch, as employed in Fig. 125, is a convenient way to explain the papermaker's ideas and desires to the machine designer. The reader is advised to accustom himself to making similar sketches of the run of the clothing through papermaking machines; by so doing, he may be able to devise possible improvements in the machines in use. The actual making of the sketch will call his attention to details that he would otherwise be likely to overlook.

387. Cylinder Tissue Machines.—The cylinder machine is exceptionally well adapted to making tissue papers that do not need to possess strength. It will be remembered that paper made on a cylinder machine is not subjected to the 'shake' action it would usually receive on a Fourdrinier machine.

A cylinder machine that is equipped for making paper is shown in Fig. 126. The paper is picked off the cylinder mold *M* by the felt *F* and is carried over a guide roll *G* and two suction boxes *B* to the nip of the press *P*, where it is passed by felt *H* from felt *F* to the receiving dryer *S* in exactly the same manner as in Fig. 124. Roll *C* is a couch roll, as on a wet machine. Dryer *S* might be a big Yankee dryer, if M. G. paper were being made.

388. Combination Machines.—A combination cylinder and Fourdrinier machine is shown in diagrammatic form in Fig. 127. This machine is designed to make **double-faced paper,** say black on one side and red on the other, or some other combination of

two colors. The total thickness of the paper need be no greater than the page on which these words are printed. The red paper, say, is formed on the Fourdrinier wire W, and it is carried from

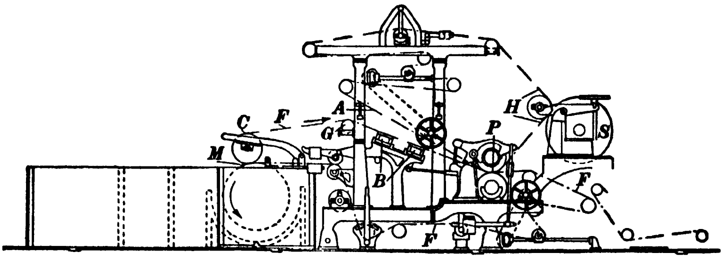


FIG. 126.

the wire by the upper felt E. The black paper is made on the cylinder C, which is on a platform below the machine-room floor. The wet felt F picks the black paper off the mold at couch

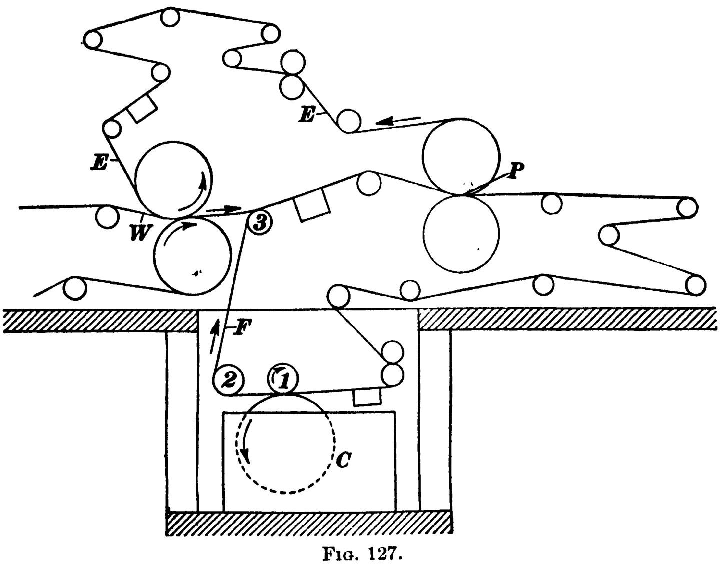


FIG. 127.

roll 1; it turns up at roll 2, and at roll 3 the black sheet meets and mates with the red paper from the Fourdrinier. As in the case of the cylinder machine, the double paper is between two felts as it enters the nip of the press rolls P. The usual guides,

felt stretchers, squeeze rolls, and suction boxes are shown in the sketch. From the press rolls P, the paper passes through other presses, if necessary, and on to the dryers.

Some of the common **duplex** papers made on this type of machine are the paper used on roll films and the blue-backed paper that is often used in making non-transparent envelopes. It is possible to combine two Fourdrinier parts in a similar way.

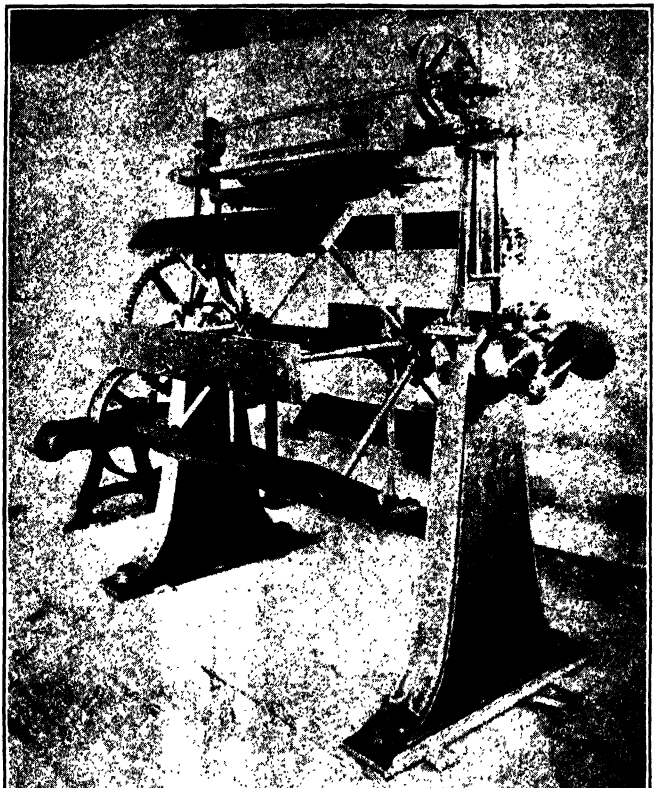


Fig. 128.

389. The Collapsible Reel.—A common accessory of a tissue machine is the **collapsible reel,** shown in Fig. 128. This is a device for maintaining a circumference of constant length on the winding roll by gradually reducing the size of the core as the roll builds up. The core is made in segments, each carried by two

brass bars that pass through the central shaft. The bars are threaded, and a gear on the shaft draws the segments *in* a little at each revolution, the amount depending on the thickness of the paper. A counter shows how many layers of paper are on the reel. Markers are put in the roll at regular intervals, say every 100 sheets. The roll at the top helps to wind the paper tight. When the roll is full, the paper is slit straight across and caught on a wheel table. The roll core is then expanded to a diameter of 4 or 5 feet, and a new roll is started. If the paper is taken directly from the machine, a small amount is necessarily wasted in changing reels, though two reels could be used if desired; or the paper could be wound first on a solid core. The flat paper is then cut into the sizes required. If the reel is working properly, all the sheets will be very nearly of the same length. Paper napkins are often handled in this manner, which is easier than with a rotary cutter.

390. Crepe Papers.—Crepe papers are usually made on one of the special machines just described. The crepe effect may be achieved on the paper machines; either single (one-process) crepe or two-process crepe may be obtained on the machine, or these effects may be secured in a separate operation. If done on the machine, the paper is brought to such a condition of wetness, by pressing or drying, that it will stick to a roll just enough to enable the doctor that removes it to wrinkle it without tearing. The paper is then dried; but it must not, of course, be pressed so hard as to remove the wrinkles. When making two-process crepe, the paper must be moistened again, and the process is then carried out as described.

INSULATING BOARD, WALLBOARD, AND HARDBOARD

391. Introductory.—The term **insulating board** embraces a wide variety of felted rigid fibrous products, ranging from bulky acoustical tiles weighing 8 lb. or less per cu. ft. to dense hardboards of a specific gravity approximating 1. During the past 15 years, this branch of the paper industry has expanded quite rapidly, until there are now over twenty machines making various forms of insulating products.

The dense *panel boards* or *hardboards*, being very compact, are relatively poor insulators. Other grades, as the so-called *insulat-*

ing lumber, range from ¼ inch to several inches in thickness, are more porous, and possess greater insulating values. Such boards have specific weights ranging from 14 to 18 lb. per cu. ft.

The important physical characteristics of *wallboard* include rigidity, high transverse and compressive strengths, water resistance, low thermal conductivity, resistance to expansion and contraction due to humidity and temperature changes, plaster bonding strength, and nail-holding power. Surface texture, ability to take paint, and hardness are also important properties.

The products of this industry are marketed in various forms, such as standard wall panels, plank, tile (either plain or grooved, and with or without special surface finishes), lath, roof insulating slabs, and moldings of various designs. In building construction, these grades are coming to be widely used as a structural building board, for inside sheathing, for outside sheathing under a finish material, for interior finish (either predecorated or as a base for paint or wallpaper or as a base for plaster), for insulating walls, roofs, and refrigerators, and for improving the acoustics of churches, halls, restaurants, offices, etc.

392. Raw Materials.—The fibers used in the insulating-board field include grasses and other annual growths, such as sugar-cane bagasse, straw, flax, corn, and also various species of wood, such as spruce, fir, aspen, poplar, gum, cottonwood, willow, southern pine, and sycamore; also, by-product chips from naval stores extraction processes and sawdust and shavings from saw mills. Rejects from groundwood plants, known as groundwood screenings, as well as old newspapers, paper boxes, etc., are also used. One manufacturer utilizes spent licorice root.

Two types of fibers are generally required to produce board having the desired properties. A coarse fiber is employed to provide the structural framework, and it is bonded together with fine groundwood or hydrated stock. In general, the boards of lower density contain a higher percentage of coarse fiber, and the proportions of fine and coarse stock are varied to meet density requirements. The insulating value of the boards is due to the voids they contain; hence, in general, the greater the void volume the more effective is the board as a barrier to the passage of heat. Steamed or semi-chemical fiber tends to make a hard board, and it usually needs some groundwood or hydrated stock as a filler.

The best insulating board generally contains from 30 to 45 per cent of fine hydrated fiber for binder, the remainder being long free fiber, up to $\frac{1}{2}$ or even $\frac{3}{4}$ inch in length. For structural building board or tile, the fiber must be shorter, in order to have greater density and a better finish. The object is to produce a combination of fibers that will stand heavy pressing and give the lowest possible moisture content to the sheet before drying, but still having the final density and thickness required.

One large manufacturer states:

The range of fiber length varies from board to board, depending on the fiber employed and the refining methods. Consequently, the following tabulation gives the range in each classification rather than specific analyses. These results were obtained from a long series of tests with a wide variety of boards, employing the Johnston classifier.

Over 14 mesh	30% to 45%
Through 14 on 28 mesh	25% to 30%
Through 28 on 48 mesh	7% to 10%
Through 48 on 100 mesh	6% to 9%
Through 100 on 200 mesh	2% to 5%
Through 200 mesh	12% to 20%

These results are fiber-length determinations on actual board, and not of stock from which the board is formed. The board stock is usually somewhat higher in the shorter fibers.

393. Stock Preparation Methods.—When vegetable fibers other than wood are used as raw material, it is always necessary to subject them to a light chemical or hot-water treatment to soften the fiber before refining. This operation is usually performed in spherical digesters, and the fiber is pulped in beaters.

When pulpwood can be used, it is ground on grinders[1] similar to those employed to make pulp for newsprint, but giving a much coarser product. Where it is necessary to use 'chips,' these are prepared by chippers, or are hogged and screened to uniform size. Generally, the chips may be defibered by the attrition-mill method of two-stage refining, after which this pulp is coarse-screened to the desired product. There are several types of *attrition mills,* some having two rotating disks, while others have one rotating and one stationary disk.

[1] Pulp grinders and refiners are fully discussed and illustrated in Vol. III.

Hammer mills have also been used for the first coarse reduction, and the resulting product then finished in an attrition mill or a Wiener type of refiner. The best hydration is obtained with hot stock at from 4 to 6 per cent consistency. The hammer mill is successfully used to reduce sawdust and shavings. The conical refiner can likewise be used on cooked vegetable fibers, and for repulping rejects or old papers, sometimes used as fillers.

The amount of power required for producing this grade of pulp depends on the product desired; in general, it is from 20 to 40 hp. per ton, according to the pretreatment employed.

The rod mill, Jordan, Wiener, and Claflin refiners have also been used. The Claflin is quite effective as a final refiner on vegetable fibers, just before the pulp enters the forming machine, corresponding with the use of Jordan with the paper machine.

In European countries, stock for hardboard manufacture is being prepared by means of a *defibrator*, which includes a plunger feed to force wood chips into a chamber where steam at 50 to 100 lb. pressure is admitted to aid the refining action. From this chamber, the steamed chips are fed by a screw conveyor to the defibrator. This unit is essentially an attrition machine that utilizes a rotating and a fixed disk with specially grooved surfaces. The defibrating action results from a rubbing or kneading action by the rotating blades within the unit, and through internal friction of the fibers forming the mass of pulp within the machine. The pulp thus produced requires further refining for some types of insulating board.

394. Exploded Fibers.—The Masonite Company has developed a unique process that involves high-pressure steam treatment, followed by quick release of pressure. The peeled or barked wood is chipped across the grain into pieces approximating $\frac{3}{4}$ inch square. After being screened, the chips are fed into a battery of 20-inch caliber guns. A gun is filled and closed, and steam is admitted until the pressure in the gun registers approximately 500 lb., which requires less than 60 sec. The pressure is then increased to upward of 1000 lb., and held at this point for a few seconds, after which the bottom valve of the gun is opened and it discharges into a 'cyclone,' where the steam and fibers separate. Some of the waste steam is used to heat process water, the remainder passing to the atmosphere. The fiber is dropped

out of the bottom of the cyclone into a stock chest, where it is mixed with water and constantly agitated. The mixture of fiber and water is now passed through refiners and piped to the main stock chest.

395. Chemical Softening.—Chemicals may be employed in cooking and softening fibers, especially for hardboards. The chemicals used are lime, caustic soda, and neutral sulphite of soda.

Raw or cooked chips are fed to a coarse refining machine with a small amount of water, and thence to several machines for final refining. In this second step, hot water is added at 160° to 200°F., and the pulp is made at 6 per cent consistency. The amount of hydration depends on the raw material, rate of feed, consistency, and temperature used.

BOARD-MAKING MACHINES

396. Forming Methods.—The development of sheet-forming equipment for this industry comprises, first, the two-cylinder type of machine; second, the single-suction cylinder; third, the high- and low-head Fourdrinier type of machine. The mold and press type of forming equipment has also been used to some extent, but it is being replaced by the continuous type of forming equipment. Wallboards may be molded in solid sheets or may be laminated. Multi-ply, or laminated, are made by pasting together 5 to 7 layers of cylinder board. The adhesive generally used is silicate of soda; starch or dextrine have also been used. Such boards are made in a variety of finishes and colors. A waterproof board is made by laminating with asphalt. Since wallboard of this type is a converting operation, the process of manufacture will not be described here.

397. The Two-Cylinder Machine.—The two-cylinder machine was one of the earliest successful machines in commercial operation. A large cylinder, Fig. 129, 6 or 8 ft. in diameter, similar to a paper-machine cylinder mold, covered with wire, is supported in a vat, with another similar cylinder supported above it at an angle of about 45°, also dipping into the vat, which is carried upward to form a considerable hydraulic head on the two cylinders. Half of the finished sheet is formed on each cylinder, and the two parts are pressed into one board on leaving the nip of the cylinders. From the forming machine, the board is carried

to the conventional-type roll press for pressing before drying. In the early days, considerable difficulty was experienced in preventing this type of board from splitting, but this trouble has now been eliminated, and speeds of approximately 20 ft. per min. on $\frac{1}{2}$-inch board are usual.

398. Single-Suction Cylinder.—This type of machine, Fig. 130, consists of a rigidly constructed cylinder, which, for purposes of controlling the vacuum application and release, is divided into multiple sections, so arranged that the vacuum can be applied to the various sections in succession. The water is drained from the several sections through internal pipes, one pipe for each section, leading to the common valve in the trunnion from

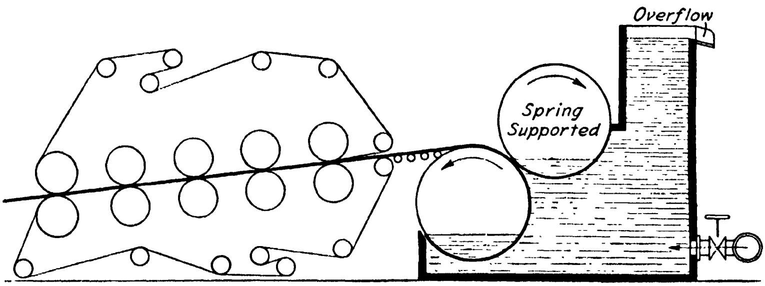


FIG. 129.

which the water is discharged. When convenient, a *barometric leg* is used to handle the water and create the vacuum. A separate vacuum pump for air is generally necessary. Usually, the machine is installed with vacuum pumps for both air and water. Consolidation of the sheet is assisted by means of press rolls, mounted on top of the cylinder mold, which may carry a felt or wire to assist in pressing the sheet. The cylinder usually has about 65 per cent submergence in the stock in the vat. The sheet is generally formed with stock at about $\frac{1}{2}$ to $\frac{3}{4}$ per cent consistency. The resulting sheet is even in formation, density, and strength in both directions, without lamination, and produces a board of relatively high bulk.

Following the forming machine, the wet sheet must be conveyed on a felt or wire to a standard roll-type press, in order further to reduce the moisture content before going to the dryer.

399. High-Head Fourdrinier Forming Machine.—An elevation of this machine is shown in Fig. 131. The wire is level, and the machine is provided with an enclosed forming chamber A, which will allow heads up to 4 ft. or more above the forming wire

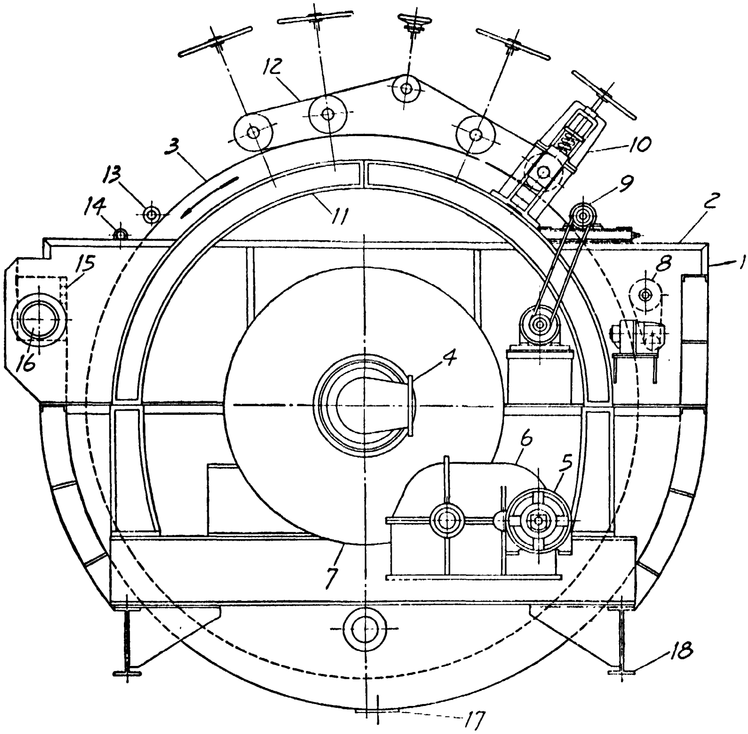


FIG. 130.—1, feed side from a suitable headbox; 2, board-machine tank; 3, board-machine drum, revolving in direction indicated by arrow; 4, vacuum connections for filtrate outlet, one on either side of drum; 5, drum drive motor, variable-speed direct-current type; 6, speed-reduction unit; 7, housing over bull-gear on drum trunnion; 8, agitator (number required depends upon character of stock); 9, brush roll; 10, four spring-loaded press rolls; 11, support for press rolls; 12, felt; 13, discharge roll with positive drive (not shown); 14, stationary shower; 15, adjustable overflow weir; 16, overflow connections, one at either end; 17, drain connection for tank; 18, supports for board machine.

B. The sheet is formed by natural drainage, assisted by the head of stock, and the board is conducted from the forming chamber by a top wire C, which holds the sheet firmly and carries it through the presses. No suction pumps or other auxiliaries are used. The outlet section D of the forming chamber, together

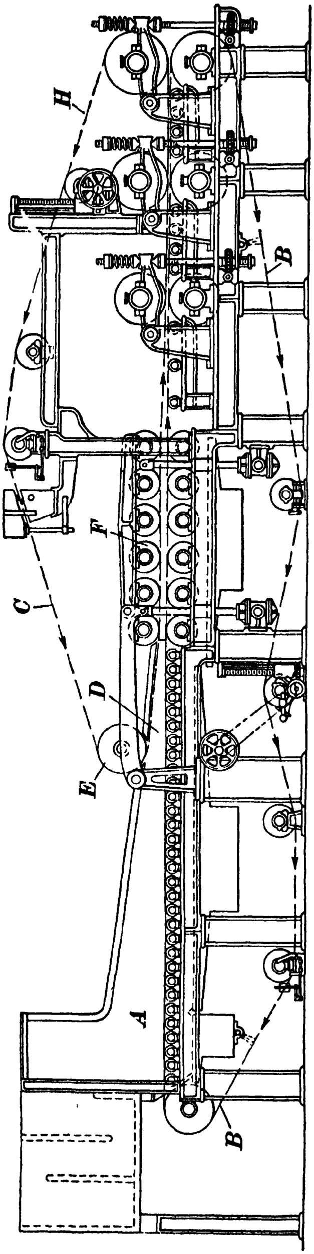


Fig. 131.

with the upper top breast roll E and rolls of the primary presses F, form a pivoted unit.

The stuff at the flow-box is about 1.15 per cent consistency. The sheet entering the press section is 14 per cent dry; it leaves this multiple-press section about 30 per cent dry. Still carried by the wire B, the sheet then passes to a second series of presses, with either a top felt or wire H, after which the sheet is about 40 per cent dry.

Low-Head Fourdrinier Forming Machine.—A Fourdrinier type of forming machine, with either stationary or traveling deckles, operates with a forming section having an adjustable slope to suit the speed and stock conditions required. This machine is generally operated with from 6 to 12 inches head of stock at the breast roll. Suction boxes are so located as to remove water from the sheet before it reaches the first-press section. Then the main-press section reduces the moisture content still further, and it is ready to be sent to the dryer. Generally, there is from 60 to 70 per cent of moisture to be evaporated by the dryers. Much of the development work in this industry has been done by the Oliver and Downington companies.

400. Hydraulic Presses.—By this method, relatively high-

consistency stock, 2 to 3 per cent, is flowed to an open press, sometimes as large as 8 by 12 ft., with wire on bottom specially reinforced by perforated platens. Close-fitting sides and ends hold the stock in place. The press is slowly closed and water is pressed through the wire, leaving the sheet formed on the wire. The plunger section may carry a reinforced drainage wire also. The press is then opened, the sheet removed on the bottom wire, and the cycle is repeated. Board coming from the press contains from 55 to 60 per cent moisture. Very careful preparation of stock is required to suit the speed of the machine; and because of limitations of speed and uniformity of thickness and density by this pressing method, it has not been widely adopted.

401. Wet Saw.—Continuous sheets are usually formed in 8 or 12 ft. widths; after they have been pressed, they are cut to lengths of 12 to 20 ft. before being fed to the drying chamber. This cutting is done automatically, when the sheet reaches a predetermined length, by a traveling cutoff saw or disk. The cutter travels at an angle or on a carriage that rides with the board, so as to cut the sheet square across. The sheets are then ready to be transferred automatically to the various decks of a multiple-deck dryer, or to storage racks for feeding the hot-plate dryers.

402. Coatings.—A large percentage of the insulating board made today is coated or surface sealed. Coatings are made with starch, casein, latex, and resinous binders, which may be pigmented with clay, lithopone, or other types of pigment. Rosin size and alum are used in nearly all grades to improve water resistance.

DRYING THE BOARD

403. Drying Methods.—Owing to the thickness of the board, it must be dried in a flat condition, and four different methods are used: (*a*) multiple-deck hot-platen dryers, stationary; (*b*) multiple-deck hot-platen dryers, moving; (*c*) tunnel dryers; (*d*) multiple-deck continuous roller dryer.

404. Stationary Platen Dryers.—These dryers are boxes with shelves or platens, and are generally used in connection with a hydraulic-press forming machine or in the manufacture of the hard pressed board. The platens may be heated by either steam or electricity; the latter, however, is too expensive unless

the electric current is exceptionally cheap. There may be 20 platens, mounted one above the other. The sheets of wet board are carried by an adjustable elevating conveyor or tipple to one shelf after another in a stationary rack, then transferred to a movable rack from which the boards are slid into the dryer press. The Masonite Company has developed a special method for feeding the platens by means of a wire cloth attached to a roller at each end of the platen, the wire winding up on the far roller as the sheet is transferred from the storage rack to these individual wires. After the press has been closed and the drying completed, the press is opened, and the wire is operated in the other direction and discharges the sheet to an empty storage tank.

Another method of loading the platens is to pick up the wet sheet on a wide conveyor that can be advanced into the opening between the platens, and to deposit the sheet onto the platen as it backs out from this opening. This operation must be repeated for each opening of the press. The press is then closed, with careful adjustment of pressure to control thickness, and the sheet is dried. The individual sheets are removed by hand to conveyors to carry them to the dry saws, where they are cut to the desired shapes. This method of drying is very satisfactory for hard-pressed board, since the larger part of the moisture is removed by pressure, which may be as high as 400 lb. per sq. in. on the sheet. The water to be evaporated can be removed in about 15 min. When using the platen press for drying the standard insulating board, it is necessary to use stops to control the thickness of the sheet, and very little pressure other than the weight of the platens themselves is needed. The water evaporated must find its way to the edge of the sheet, and this usually requires from 40 to 50 min. drying time.

405. Moving Platen Dryers.—In another system, steam-heated cast-iron platens are mechanically closed on a board, and opened for the board to be moved forward; a section of the dryer is intermittently closed on the board and moved forward. Hence the board advances through the dryer, and the moisture is permitted to escape from the board during this opening, or 'breathing,' operation. This requires rather an elaborate mechanical equipment for operation, is efficient in drying, and is very desirable for a certain class of products where a smooth surface is desired.

The dryer is enclosed in an insulated chamber, and fans are used to circulate the air and remove moisture. These dryers may be 8 or more decks in height.

406. Tunnel Dryers.—These dryers are composed of a well-insulated sheet-metal tunnel or large box, through which the board is passed on a series of small driven rolls, with or without top rolls on them. They usually consist of three different sections. In the first section, the board is brought to a high temperature, say 400° to 500°F., by circulating very hot air. In the middle section, the temperature is still very high. In the third section, the board is approaching dryness, and the heat is reduced to avoid danger of burning it. If only one sheet of ½-inch board is passed through this dryer, it should be at least 1000 ft. in length.

Most dryers are built in 8 or 10 tiers, superimposed above each other, with an automatic feeder and wet saw, which cuts the board into 12- or 16-ft. lengths and feeds one sheet into each tier of the dryer in turn; thus the board in the dryer advances at a fraction of the speed of the wet end, corresponding to the number of tiers.

407. Multiple-Deck Continuous Roller Dryer.—This type is more used than any of the others in drying insulating board. It consists of an automatic wet-saw unit, a transfer tipple and feed section,

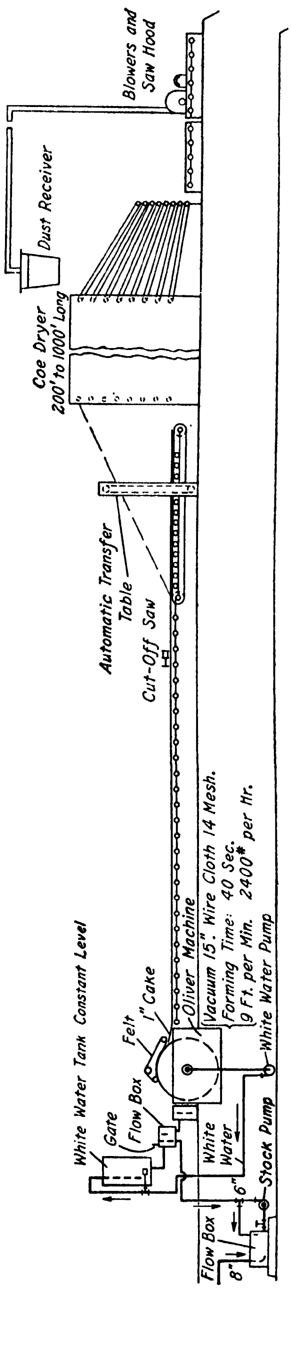


Fig. 132.

then, usually, an 8-deck drying section with driven rolls on 4- to 12-inch centers supporting the sheets, steam coils for heating, and fans circulating hot air and removing the moisture. There is also a cooling and unloading section for delivering the dried sheets to the saw tables to be cut into commercial shapes. The dryer section is enclosed and well insulated, and is from 200 to 500 ft. in length; but where single-deck dryers are used, this section is from 800 to 1000 ft. long, and the sheet need not be cut until dried. The steam temperature in the dryer section is from 300° to 500°F., depending on the material and conditions. This machine is shown diagrammatically in Fig. 132.

APPENDIX

PAPER-PRODUCTION CALCULATIONS

408. Paper-Machine Efficiency.—The output of a paper machine may be expressed in three ways: (*a*) **Capacity production** is the total possible amount of paper that can be made with the maximum width and without allowance for any losses, such as lost time for wash-ups, changing wires and felts, mechanical breakdowns, breaks in the paper. (*b*) **Gross production,** or simply **production** or **machine production,** as usually termed, is the total amount of paper actually made. (*c*) **Net production** is the amount of salable paper, after *culls* (defective paper) have been deducted; it may be defined as the paper delivered from the machine, and would be calculated from the sum of the widths of the rolls wound or of the sheets cut (in the case of boards or of paper to be loft dried).

Paper that does not get wound is *broke.* If this loss occurs at the wire or wet presses, it is *wet broke;* if at the dryers, calenders, or winders, it is *dry broke,* whether lost because of trim or spoilage. This machine broke can be calculated from the machine speed, width of paper, ream weight, and unproductive machine time.

The ratio between net production and capacity production is a measure of the machine performance; it may be called the **machine efficiency,** and is expressed as

$$\text{Machine efficiency } (\eta) = \frac{\text{net production } (N)}{\text{capacity production } (C)}$$

For example, a 226-inch newsprint machine might have a maximum trim of 210 in. (3 70-inch rolls) and a maximum speed of 1200 ft. per min. Its daily (24-hr.) capacity production of 32-lb. standard-ream paper is

$$C = \frac{720 \times 226 \times 1200 \times 32 \times 24}{500 \times 24 \times 36} = 347{,}136 \text{ lb.}$$

But if the publisher wanted 68-inch rolls, the actual speed was 1000 ft. per min., and the time lost was 30 min., and there were no culls, the net production would be

$$N = \frac{720 \times 3 \times 68 \times 1000 \times 32 \times 23.5}{500 \times 24 \times 36} = 253{,}680 \text{ lb.}$$

and the machine efficiency would then be

$$\eta = \frac{N}{C} = \frac{253680}{347136} = 0.73 = 73\%$$

409. Weight of Paper Made per Hour.—The weight of paper made per hour, based on the weight of a ream of given size and count, is easily calculated when the speed of the machine (*i.e.*, speed of paper through the machine) and the width of the sheet[1] are known. Thus, let

D = width of sheet (actual trim) in inches;
d = width of ream in inches (measured across the machine);
l = length of ream in inches (measured in direction of run);
r = ream count (usually 500 or 480 sheets);
S = speed of machine in feet per minute;
W = weight of ream in pounds;
P = production in pounds per hour.

The area in square inches of paper made per hour is evidently equal to the sheet width times the speed of the machine in inches per minute times 60, or $D \times S \times 12 \times 60 = 720DS$. The area in square inches of the paper in a ream is $d \times l \times r = dlr = rdl$. The number of reams made per hour is $720DS \div rdl$; its weight is $(720DS \div rdl)W$; hence, the production in pounds per hour is

$$P = \frac{720DSW}{rdl} \qquad (1)$$

[1] These calculations refer to actual production of the paper delivered from the machine, and the *width of the sheet* is the net width at the winder after the shaving is trimmed off: this is also called *actual trim*. The *gross width*, or *capacity trim*, is the widest possible width with a new wire on the machine and deckle straps or boards as far out as possible, measured at the reel. The actual trim might be reduced by narrow orders, defects in wire or felts, etc. Where the width of the paper on the machine is taken as the sum of the individual sheets to be cut from it, size of ream is used. *Deckle width* is really the width of the paper on the wire, but this term is sometimes used in referring to the width at the reel. The squirts will take off from the deckle width at least 2 in., and the sheet will shrink about 3 per cent (for newsprint). On a cylinder machine, the trim is measured at the reel or in front of the sheet cutter.

For a ream of 480 sheets,

$$P = \frac{720DSW}{480 \times dl} = \frac{1.5DSW}{dl} \tag{2}$$

For a ream of 500 sheets,

$$P = \frac{720DSW}{500dl} = \frac{1.44DSW}{dl} \tag{3}$$

Formula (1) is perfectly general and applicable to all cases; but when the ream count is 500 or 480 sheets, formulas (3) and (2) are more convenient. If, in addition, the production be desired in terms of a standard ream of 24 × 46—500, formula (3) may be still further simplified. Thus, substituting 24 × 36 for dl,

$$P = \frac{1.44DSW}{24 \times 36} = \frac{DSW}{600}. \tag{4}$$

That is, the production in pounds per hour of a standard ream of 500 sheets is equal to the continued product of the sheet width, D, the speed in feet per minute, S, and the weight of a ream in pounds, W, divided by 600. For example, suppose a machine is running at 625 ft. per min., that the sheet width is 160 in., and that it is making paper weighing 30 lb. per ream of 24 × 36—500; then, using formula (4), the production is

$$P = \frac{160 \times 625 \times 30}{600} = 5000 \text{ lb. per hr.}$$

If the ream count were 480 instead of 500 sheets, substitute in formula (2), and

$$P = \frac{1.5DSW}{24 \times 36} = \frac{DSW}{576} \tag{5}$$

For ease of calculation, formula (5) may be written

$$P = \frac{DSW}{600} + \frac{1}{24}\left(\frac{DSW}{600}\right) \tag{6}$$

To get one-twenty-fourth of a number, simply divide by 4 and then divide the quotient by 6. For instance, if the ream count in the example above had been 480 instead of 500 sheets, calculate

the production as above, obtaining 5000 pounds per hour. Dividing this by 4, the quotient is 1250; dividing this quotient by 6, the new quotient is 208+. Then, 5000 + 208 = 5208 pounds per hour for 30-pound, 24 × 36—480, under the conditions named. That this is correct may be proved by substituting in formula (5), obtaining

$$P = \frac{160 \times 625 \times 30}{576} = 5208 \text{ lb. per hr.}$$

It is understood, of course, that formulas (4), (5), and (6) can be used only for standard reams and ream counts of 500 or 480 sheets.

410. Equivalent Reams.—It may be desired to calculate the production in terms of a ream of a certain size, weight, and ream count, regardless of whether either dimension of the ream is an exact divisor of the sheet width. Thus, suppose it is desired to know the production of a machine having a sheet width of 123 inches and a speed of 350 feet per minute, based on 45-pound book paper, 25 × 38—480. Substituting in formula (2),

$$P = \frac{1.5 \times 123 \times 350 \times 45}{25 \times 38} = 3059 \text{ lb. per hr.}$$

The result just obtained (and the results previously obtained) is based on the assumption that *all* the paper made is turned into reams of a certain size and weight. This, however, is not the case, since there is always a loss due to cutting and trimming, to defective sheets, etc. This loss varies considerably, even on the same run, and from hour to hour; hence, the exact output of *trimmed paper* can be found only approximately. The output may be calculated by one of the foregoing formulas, and then a certain per cent of it may be deducted, the amount depending on the grade of paper and manufacturing conditions and on the judgment and experience of the person who makes the calculation.

It is also frequently desirable to express reams of one size and weight in terms of reams of another size and weight. In this case, the production, sheet width, and speed of the machine remain the same. Letting W', r', l', and d' represent the weight of the ream, ream count, and length and width of the sheet under the new conditions, and using formula (1) of Art. **409**,

$$P = \frac{720DSW}{rdl} = \frac{720DSW'}{r'd'l'}$$

from which

$$W' = \frac{r'd'l'}{rdl}W \qquad (1)$$

If the ream count is also the same, $r' = r$, and

$$W' = \frac{d'l'}{dl}W \qquad (2)$$

For example, what will be the corresponding weight of a 25 × 38—480 ream, if a standard 24 × 36—500 ream weighs 30 pounds? Substituting in formula (1),

$$W' = \frac{480 \times 25 \times 38}{500 \times 24 \times 36} \times 30 = 31.67 \text{ lb.}$$

A further discussion of this subject is given in the Section on *Paper Testing*.

411. Changing Deckle Width and Speed or Weight.—Assuming that the flow of stock to the wire is constant, if the deckle width is narrowed, say, and the speed of the wire is unchanged, there will be a thicker covering on the wire, and the weight of the sheet will be more. If the weight of the paper is to be kept uniform, the speed of the machine must be increased. But if the deckle width is increased, the speed of the machine must be decreased, if the weight of the paper is to be kept uniform. In either case, it is assumed that the production is constant, which must be the case if the same amount of stock per unit of time is supplied to the machine. While all three factors, D, S, and W, may be changed, it is usually customary to change only two of them; and it is assumed that the size of the sheet and the ream count are constant. Letting D', S', and W' represent the new values,

$$P = \frac{720D'S'W'}{rdl} = \frac{720DSW}{rdl}$$

from which,

$$D'S'W' = DSW$$

From this equation,

$$S' = \frac{DSW}{D'W'} \qquad (1)$$

and when $W = W'$,

$$S' = \frac{DS}{D'} \qquad (2)$$

If $D = D'$,

$$S' = \frac{SW}{W'} \qquad (3)$$

For instance, referring to the example of Art. **410,** suppose it were desired to push in the deckle 3 inches, reducing the sheet width to 120 inches, but keeping the weight and size per ream constant; what would be the speed of the machine? Using formula (2),

$$S' = \frac{123 \times 350}{120} = 359 \text{ ft. per min.}$$

EXAMPLE.—A machine is making paper 24 × 36—500, 30-lb. at 625 ft. per min., the sheet width being 160 in. and the production 5000 lb. per hr. It is desired to make 32-lb. paper, with the same production and sheet width; what should be the speed?

SOLUTION.—Since the only factors changed are the speed and weight per ream, use formula (3), and

$$S' = \frac{625 \times 30}{32} = 586 \text{ ft. per min.} \quad Ans.$$

412. Finding the Speed.—When the machine is equipped with a tachometer that derives its motion from the last dryer or from the paper, the speed of the paper[1] in feet per minute is read direct from the instrument. If there is no tachometer, the speed may be obtained with greater or less accuracy by one of the two following methods:

FIRST METHOD.—Count the number of revolutions made per minute by the *last* dryer. Knowing the diameter of the dryer, its circumference can be found, and this multiplied by the number of revolutions per minute gives the speed in feet per minute, the circumference being taken in feet; the speed thus found may be assumed to be the same as the speed of the paper, roughly. In

[1] By 'speed of the paper' is meant the speed of the *finished* paper.

practice, a mark may be placed on the end of the dryer, and the number of times it returns to a selected position or passes a stationary point will be the number of revolutions of the dryer. Since the dryer turns fairly slowly, comparatively speaking, it is best to count the revolutions for, say, 5 minutes, and divide the result of the count by the number of minutes. Or, count, say, 100 revolutions, take the time in seconds, divide $100 \times 60 = 6000$ by the time in seconds, and the quotient will be the revolutions per minute. Thus, if d = diameter of dryer in feet,

$$S = \frac{6000\pi d}{t}$$

t being the time in seconds required by the dryer to make 100 revolutions. For instance, if the diameter of the dryer is 5 feet, and it takes 150 seconds (= 2 minutes 30 seconds) for the dryer to make 100 revolutions, the speed of the machine is

$$S = \frac{6000 \times 3.1416 \times 5}{150} = 628 \text{ ft. per min.}$$

Somewhat more accurate results will be obtained by applying this method to the *bottom calender roll;* because, when measurements are taken at any previous point, the *stretch* of the paper between this point and the calenders is not considered in the above calculation. The diameter may be obtained with calipers, or the circumference may be found with a steel tape.

413. Alternative Method.—Instead of finding the speed in feet per minute, an alternative method is to count the number of strokes per minute of the knife cutting the paper. This method is applicable to loft-dried papers and cut boards. Then, let

N = number of strokes of knife per minute;

n = number of sheets cut per stroke.

The area of the paper cut is $d \times l \times n \times N \times 60$ square inches per hour. The number of reams cut per hour is $\dfrac{dlnN \times 60}{rdl}$ $= \dfrac{60nN}{r}$; and the production in pounds per hour is

$$P = \frac{60nNW}{r} \qquad (1)$$

This formula is exactly equivalent to formula (1) of Art. **409**, which may be written $60 \times \frac{D}{d} \times \frac{12S}{l} \times \frac{W}{r} = \frac{720DSW}{rdl} = P$. But $\frac{D}{d} = n$, and $\frac{12S}{l} = N$; hence, substituting,

$$P = 60 \times n \times N \times \frac{W}{r} = \frac{60nNW}{r}$$

For a ream count of 480 sheets, formula (1) reduces to

$$P = \frac{nNW}{8} \qquad (2)$$

For a ream count of 500 sheets, formula (1) reduces to

$$P = 0.12nNW \qquad (3)$$

The three formulas here given are very convenient; and it will be noted that the size of the sheet is not required.

Example.—A machine is making 45-lb. bond paper; the number of strokes of the knife per minute is 88, and the number of sheets cut per stroke is 5. The ream count being 480, what is the production of finished paper in pounds per hour?

Solution.—Since the ream count is 480, use formula (2), and

$$P = \frac{5 \times 88 \times 45}{8} = 2475 \text{ lb. per hr.} \quad \textit{Ans.}$$

414. Production of Board on Cylinder Machine.—Formula (1) of Art. **409** is perfectly general and may be used to calculate the production of any machine and any kind of paper. But, under certain conditions, the formula may be still further simplified, as in the case of the cylinder machine, the product of which is always specified in **bundles** that weigh 50 pounds each, irrespective of the size of the sheet (board). Hence, formula (1) of Art. **409** may be written

$$P = \frac{720DS \times 50}{bdl} = \frac{36{,}000DS}{bdl} \qquad (1)$$

in which b = the number of sheets or boards in a bundle.

The common (mill) standard[1] sheet for board is 30 × 40 inches (just as the standard sheet for a ream of paper is 24 × 36 inches);

[1] The *official standard* size is 25 × 40 (see Arts. **420–424**); this gives the regular number, R.N., in a bundle.

hence, the production of a cylinder machine in pounds per hour making standard sheets is

$$P = \frac{36{,}000DS}{30 \times 40 \times b}$$

from which

$$P = \frac{30DS}{b} \qquad (2)$$

EXAMPLE 1.—What is the production of a cylinder machine running 150 ft. per min. and making board 30 × 40—90 (this means sheets 30 × 40 inches, 90 of which make a bundle weighing 50 pounds), the sheet width being 120 in.?

SOLUTION.—Substituting in formula (2),

$$P = \frac{30 \times 120 \times 150}{90} = 6000 \text{ lb. per hr.} \quad \textit{Ans.}$$

EXAMPLE 2.—What is the actual production of a machine running 150 ft. per min., having a sheet width of 120 in., and making board $22\frac{1}{2} \times 29$—184?

SOLUTION.—Since this is not the standard size, and since $4 \times 29 = 116$ inches is the greatest width of trim that can be used, substitute in formula (1), using 116 for the sheet width. Then,

$$P = \frac{36000 \times 116 \times 150}{184 \times 22.5 \times 29} = 5217 \text{ lb. per hr.} \quad \textit{Ans.}$$

415. Special Sizes.—Suppose that a customer wishes to order board of a certain thickness, which is the same as one of the sheets of a standard bundle, the number of sheets in which is known; but that he wants the board to be a special size. Instead of ordering a certain number of bundles, he will order a certain number of sheets, and it will be up to the papermaker to determine the number of bundles required to fill the order. Remembering that the weight of any bundle is always 50 pounds regardless of the size of the sheet, and since the weight of a cubic inch of the paper in the bundle is then always the same, it may be assumed that the volume of all bundles is constant. Letting t = the thickness of a sheet, the volume of a standard bundle is $30 \times 40 \times bt = 1200bt$; the volume of a bundle of special-size sheets is $d' \times l'b't = d'l'b't$; and since the two volumes are equal, $d'l'b't = 1200bt$, from which

$$b' = \frac{1200b}{d'l'} \qquad (1)$$

That is, to find the number of sheets in a bundle of special size, multiply 1200 by the desired number of sheets in the standard bundle and divide the product by the area of the special sheet. For instance, to find the number of sheets $22\frac{1}{2} \times 29$ in a bundle, the sheets to correspond to those in a standard bundle containing 100 sheets, apply formula (1),

$$b' = \frac{1200 \times 100}{22.5 \times 29} = 184 \text{ sheets}$$

Let N = the number of sheets ordered;
n = the number of bundles that will contain N sheets; then,

$$n = N \div b' = N \div \frac{1200b}{d'l'}$$

or,

$$n = \frac{N}{b'} = \frac{Nd'l'}{1200b} \qquad (2)$$

EXAMPLE.—A customer orders 6000 sheets of $22\frac{1}{2} \times 29$ on the basis of 30×40—100; how many bundles will it take to fill this order, and what is the weight?

SOLUTION.—Applying formula (2),

$$n = \frac{6000 \times 22.5 \times 29}{1200 \times 100} = 32\tfrac{5}{8}, \text{ say 33 bundles.[1]} \quad \textit{Ans.}$$

$$\text{Weight} = 33 \times 50 = 1650 \text{ pounds.} \quad \textit{Ans.}$$

Further data concerning board calculations will be found in Arts. **420–440.**

416. Finding Weight of a Ream.—The weight of a ream of paper is found by weighing a single sheet on a suitable scale. If the scale records the exact weight of the sheet, this weight multiplied by the ream count, usually 480 or 500, gives the weight of the ream. Special paper scales may be obtained that give the ream weight direct; a scale of this kind is shown in Fig. 133. Here H is a holder for the paper sheet, which is cut to the exact size, generally by using a template. The template is a metal plate, which is laid on the paper, and the paper is best cut with a sharp knife, but it is sometimes torn, following the edges of the

[1] This result might also have been obtained by dividing 6000 by the number of sheets in a bundle, which, as found above, was 184; thus, 6000 ÷ 184 = 32.61, say 33 bundles.

template. The holder H is suspended from one arm of a bell-crank lever AB. As the holder moves down, owing to the weight of the paper, the other arm A of the lever swings through an arc the length of which depends upon the weight of the sheet. The arm A has an opening at the lower end, across which is stretched

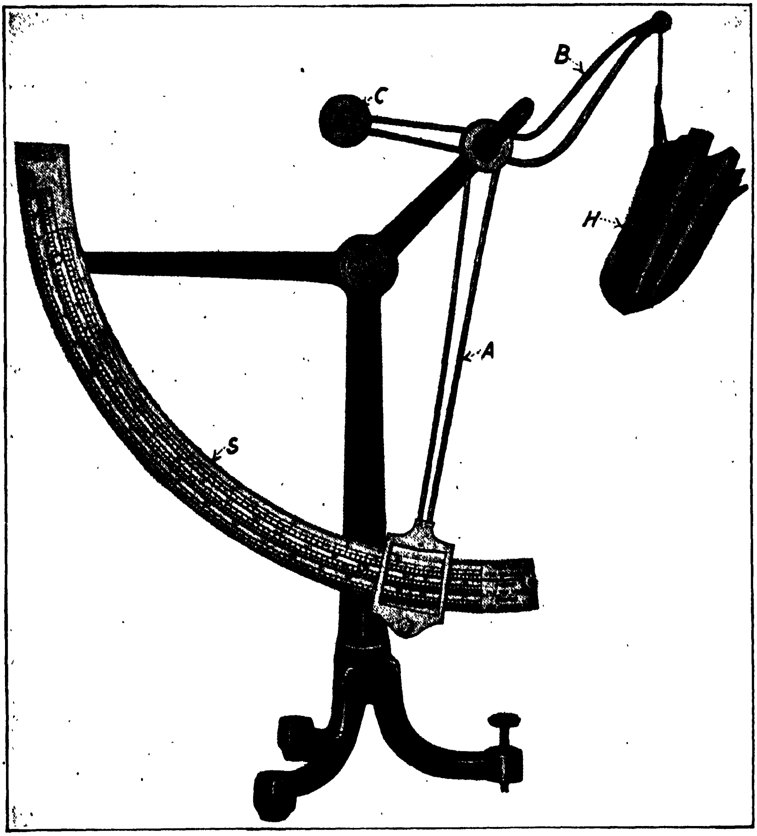


FIG. 133.

a fine wire. S is a stationary quadrant that contains two scales, one of which records 480 times the weight of the sheet in the holder, and the other scale records 500 times this weight—both in pounds. The reading under the wire gives the weight of a ream of either 480 or 500 sheets. C is a counterpoise to balance the weight of the holder H and make the scale more sensitive. A

third scale may be arranged to give the weight of 516 sheets, or to read in grams per square meter.

417. Standard Sizes.—Papers may be divided roughly into three general classes: rough papers, as newsprint, hanging paper (wallpaper), wrappings, tissues, etc.; book papers; and fine papers, as writings, etc. Boards are not included in the foregoing. It should be noted that any one mill seldom makes more than one of these three classes of papers; that is, a mill or a machine may make newsprint and wrappings or tissue only, or it may make book papers, or it may make fine papers, but it does not usually make more than one of these classes. For this reason, principally, since there are all sizes of paper in each general class, there are three standard sizes, which are: for newsprint, etc., 24 × 36; for book papers, 25 × 38; for fine papers, 17 × 22, all dimensions being in inches. Calculations for hanging paper require the use of a special constant; see Art. **419.**

The necessity for having a standard size should be obvious. The machine tender must have a guide in determining the amount of stock that flows on the wire, or rather, the thickness of the stock on the wire, and this he can approximate as soon as he knows the weight of a sheet of a size that he is accustomed to handling. Hence, no matter what the size of the sheet ordered, the ream count, and weight of the ream, it can readily be transformed to the weight of an equivalent ream of standard size and ream count by the methods of Art. **410.**

For several years past, there has been a strong movement toward replacing all three of the above standards with a single standard of 25 × 40—500, and it is to be hoped that this standard will be generally adopted. Among the other advantages are that the area of the sheet is 1000 square inches, an easy number to remember and to handle. See also Section 5.

418. Metric Measurements.—In countries using the metric system, the size of the sheet is expressed in centimeters; the weight may be expressed either as so many grams per square meter or as so many kilograms for a certain number of sheets, say 500. To convert grams per square meter into pounds per ream, proceed as follows:

1 pound per square inch = 703,071 grams per square meter; but for all problems concerning the weight of a ream of paper,

w = 1 pound per square inch = 703,100 grams per square meter. The value of w for any particular ream of paper is

$$w = \frac{W}{rdl} \text{ pounds per square inch}$$

in which the letters in the right-hand member have the same meaning as in Art. **409.** If the weight in grams per square meter be represented by M,

$$M = \frac{703100W}{rdl} \text{ grams per square meter} \qquad (1)$$

and

$$W = \frac{rdlM}{703100} \text{ pounds per ream} \qquad (2)$$

If the values for the several standard sizes be substituted in these formulas for r, d, and l, they reduce to very simple expressions. Thus,
For 25 × 40—500,

$$M = \frac{703100W}{500 \times 25 \times 40}$$

or

$$M = 1.406W \qquad (3)$$
$$W = 0.7111M \qquad (4)$$

For 25 × 38—500,

$$M = 1.48W \qquad (5)$$
$$W = 0.6756M \qquad (6)$$

For 24 × 36—500

$$M = 1.627W \qquad (7)$$
$$W = 0.6144M \qquad (8)$$

For 17 × 22—500,

$$M = 3.76W \qquad (9)$$
$$W = 0.266M \qquad (10)$$

If desired, a similar set of formulas may be obtained for a ream count of 480.

EXAMPLE.—A manufacturer of paper receives an order for 500 reams of 64 cm. × 96 cm.—500, the weight of the paper to be 67 grams per square meter. The dimensions given are in centimeters; what is the weight in pounds per ream of standard 25 × 38—500, and what is the total weight of the order?

SOLUTION.—Using formula (6), $M = 67$, and

$$W = 0.6756 \times 67 = 45.3 \text{ lb. per ream.} \quad \textit{Ans.}$$
$$\text{Total weight} = 45.3 \times 500 = 22{,}650 \text{ lb.} \quad \textit{Ans.}$$

In problems of this kind, it is inadvisable to use more than three significant figures when expressing the weight of a ream.

If the number of sheets per ream is the same for both metric and English units, the factors just given are applicable.

In some cases, the order may call for a certain number of kilograms, the dimensions of the sheet being in centimeters, and the weight expressed as so many kilograms for, say 500 sheets. Let r, d, l, and W represent the same values as in Art. **409**; let r' be the ream count in the order, d' and l' the dimensions in centimeters, and K the weight of the ream in kilograms. Then the weight of a sheet in pounds per square inch is $\frac{W}{rdl}$, the weight in kilograms per square centimeter is $\frac{K}{r'd'l'}$, and since 1 kilogram per square centimeter = 14.223 pounds per square inch, $14.223 \times \frac{K}{r'd'l'} = \frac{W}{rdl}$, from which

$$W = \frac{14.223rdlK}{r'd'l'} \qquad (11)$$

If $r' = r$,

$$W = \frac{14.223dlK}{d'l'} \qquad (12)$$

EXAMPLE.—A manufacturer of newsprint receives an order for 160,000 kilograms of paper, 74 × 90—16 kg./500; that is, the size of the sheet is to be 74 by 90 cm., and the weight is to be 16 kilograms for 500 sheets. (*a*) What is the weight of a standard ream 24 × 36—500? (*b*) What is the weight in grams per square meter? (*c*) How many reams will it take to fill the order?

SOLUTION.—(*a*) Substituting in formula (12),

$$W = \frac{14.223 \times 24 \times 36 \times 16}{74 \times 90} = 29.5 \text{ lb./ream.} \quad \textit{Ans.}$$

(*b*) Substituting in formula (7),

$$M = 1.627 \times 29.5 = 48 \text{ g./m.}^2 \quad \textit{Ans.}$$

(*c*) The number of reams is $160{,}000 \div 16 = 10{,}000$ reams. *Ans.*

419. Hanging Paper.—Hanging paper and newsprint are very similar in composition, but hanging paper usually contains less sulphite pulp. Hanging paper when printed or otherwise processed is called **wallpaper.**

The basis weight of hanging paper is the weight in ounces of a **roll** 20 inches wide and 9 yards long. In Canada and England the width is 22 inches. The weight of such a roll may be 10, 12, 14, 16, 18, or 20 ounces, and the rolls would be, respectively, designated as 10-, 12-, 14-, 16-, 18-, and 20-ounce paper. Another size frequently used, called a *wide roll*, is 30 inches wide (in Canada, 29½ inches; and the weights run from 8 oz., or 34 lb., to 24 oz., or 98 lb.) and 5 yards long. A new standard width is 19⅞ inches, the length being the same as for the 20-inch roll. When making the paper, the machine tender must know the basis specified, and he must make the proper allowance for it.

Given the basis weight, the machine tender transforms it into the weight in pounds of a ream of standard newsprint 24 × 36—500, or someone else must do it for him. The first step is to find how much a standard ream of the same paper would weigh. The weight of a ream will be as many times greater than the weight of the roll, as the total area of the paper in the ream is greater than the total area of the paper in the roll. Consequently, let

w = weight of roll in ounces;
a = area of roll = $9 \times 36 \times 20$ square inches;
A = area of ream = $24 \times 36 \times 500$ square inches;
W = weight of ream in pounds;

then, $\frac{w}{16}$ = weight of roll in pounds, and, by proportion,

$$W : \frac{w}{16} = A : a, \text{ or } W = \frac{wA}{16a} = \frac{A}{16a}w$$

Substituting the values of A and a,

$$W = \frac{24 \times 36 \times 500}{16 \times 9 \times 36 \times 20}w$$

or

$$W = 4\tfrac{1}{6}w \qquad (1)$$

In other words, the weight of a ream in pounds is equal to $4\frac{1}{6}$ times the weight of the roll in ounces; in mill practice, however, it is customary to use the constant 4 instead of $4\frac{1}{6}$, in which case, the weight of a standard ream 24 × 36—500 is figured as 4 times the weight of the 20-inch roll in ounces.

In the case of the wide roll, the area is 5 × 36 × 30, and this divided by the area of the 20-inch roll gives $\frac{5 \times 36 \times 30}{9 \times 36 \times 20} = \frac{5}{6}$; that is, the area of the wide roll is five-sixths ($\frac{5}{6}$) the area of the 20-inch roll. A wide roll of 18-ounce paper will therefore weigh $18 \times \frac{5}{6} = 15$ ounces; also, a wide roll weighing 10 ounces will be made up of $10 \times \frac{6}{5} = 12$-ounce paper.

For the $19\frac{3}{8}$-inch roll, substitute $19\frac{3}{8}$ ($= \frac{155}{8}$) for 20 in the equation $W = \frac{A}{16a}w$, obtained above, and

$$W = \frac{24 \times 36 \times 8 \times 500}{16 \times 9 \times 36 \times 155}w$$

or

$$W = 4.3w \qquad (2)$$

Hence, the weight of a standard ream of 16-ounce paper in a $19\frac{3}{8}$-inch roll is $4.3 \times 16 = 68.8$ pounds; in a 20-inch roll, the weight of a standard ream is $4\frac{1}{6} \times 16 = 66.67$ pounds.

It is better to use the constant $4\frac{1}{6}$ instead of 4 for the 20-inch roll; and if this be used in calculating the weight of a ream for a 20-inch roll, the weight for a $19\frac{3}{8}$-inch roll may be obtained very closely by adding 3%, since $\frac{4.3 - 4\frac{1}{6}}{4\frac{1}{6}} = 0.032 = 3.2\%$.

Having found the weight of a standard ream, the production in pounds per hour may be ascertained by applying formula (4) of Art. **409.**

If only the production in pounds per hour be desired, simply substitute $4\frac{1}{6}w$ for W in formula (4) of Art. **409,** which then reduces to

$$P = \frac{DS \times 4\frac{1}{6}w}{600}$$

from which,

$$P = \frac{DSw}{144} \qquad (3)$$

EXAMPLE 1.—Find the production in pounds per hour of a machine making 16-oz. hanging paper, the paper measuring 81 in. on the reel, and the speed of the machine being 300 ft. per min.

SOLUTION.—The width of the paper on the reel equals the sheet width. Applying formula (3),

$$P = \frac{81 \times 300 \times 16}{144} = 2700 \text{ lb. per hr.} \quad \textit{Ans.}$$

EXAMPLE 2.—A machine is making 14-oz. paper in rolls $19\frac{3}{8}$ in. wide the speed of the machine is 350 ft. per min., and the paper measures 117 in. on the reel. (*a*) What is the weight of a standard sheet? (*b*) What is the production in pounds per hour?

SOLUTION.—(*a*) Applying formula (2),

$$W = 4.3 \times 14 = 60.2 \text{ lb.} \quad \textit{Ans.}$$

(*b*) Applying formula (3),

$$P = \frac{117 \times 350 \times 14}{144} = 3981 \text{ lb. per hr.}$$

As was previously shown, this result must be increased by 3%; hence, the production is 3981 $\times$ 1.03 = 4100 lb. per hr. *Ans.*

Or, applying formula (4) of Art. **409**,

$$P = \frac{DSW}{600} = \frac{117 \times 350 \times 60.2}{600} = 4109 \text{ pounds per hour.} \quad \textit{Ans.}$$

The slight difference in the two answers is due to the fact that the increase is really 3.2% instead of 3%; but this difference is negligible in practice.

PAPERBOARD STANDARDS

The following standard rules and regulations have been adopted by the National Paperboard Association,[1] representing the United States manufacturers of paperboard for use in corrugated and solid fiber boxes and folding and setup boxes.

DEFINITIONS

420. Standard Sizes.—The **standard size** of all grades is 25 $\times$ 40 inches, containing 1000 square inches. Patent coated

[1] By permission of the publishers, Arts. **420–441** have been extracted from their publication, Standards, copyright, 1934.

or manila boards (Lists 6 to 8) are also shown in sizes 24 × 36 in. (864 sq. in.) and 28 × 44 in. (1232 sq. in.). The standard sizes are used as bases for all computation.

421. Standard Package.—A **standard package** of patent coated or solid manila board is a ream of 500 sheets. For convenience, these grades are sometimes packed in fractions or multiples of a ream, depending on the size of the sheet.

422. Bundle.—A **bundle** is a unit containing 50 pounds. The quantity (number) of sheets varies with the size and the caliper, but the weight of board in a bundle is fixed at 50 lb.

423. Regular Numbers.—The number, or **regular number** (R.N.), is the quantity of standard-sized sheets (25 × 40) of box board required to make a bundle of 50 pounds.

424. Count.—The **count** is the number of odd-sized sheets required to make a bundle. If the sheets are standard size (25 × 40), the count is identical with the regular number; therefore, it has become the custom to use the term 'count' to apply only to odd-sized sheets, and 'regular number' to standard-size sheets.

The area in square inches of the board in a bundle of a regular number is the regular number (R.N.) multiplied by 1000. The count for odd-sized sheets is found as follows: given the kind, finish, and caliper of the board, ascertain from the proper gauge list (one of the following tables) the R.N. of such board, multiply the R.N. by 1000, and divide the product by the area in square inches of the odd-sized sheet (width multiplied by length).

Example.—What is the count for plain chipboard, 20 × 35, No. 2 finish, caliper, .032?

Solution.—Referring to No. 1 Gauge List, the R.N. for No. 2 finish and .032 caliper is 65; hence, $\frac{65 \times 1000}{20 \times 35} = 93$ = count of odd-sized sheet, or 93 sheets in bundle. *Ans.*

425. To Find Regular Number.—Knowing the size of the odd-sized sheet and the count, let d = width and l = length of sheet in inches and C = the count; then,

$$\text{R.N.} = \frac{Cdl}{1000}$$

Example.—What is the regular number for bending chipboard, 20 × 35, and 107 count?

SOLUTION.—Substituting in the preceding formula the values given,

$$\text{R.N.} = \frac{107 \times 20 \times 35}{1000} = 75. \quad \textit{Ans.}$$

426. Caliper.—**Caliper** is the thickness of board expressed in thousandths of an inch ($\frac{1}{1000}$ in.) and written as a decimal of an inch. A **point** is .001 in.

427. Finish.—There are four standard finishes, designated by numbers 1 to 4, the lowest to the highest. The degree of finish is regulated by the pressure exerted on the calenders through which the board passes. The pressure determines the density of the sheet. The resulting surface is incidental, but it gains in smoothness as the calender pressure is increased.

Number 1 finish: Light pressure, resulting in a rough surface and low density. It gives large sheetage for its weight; *i.e.*, it has most area per pound of board.

Number 2 finish: Medium pressure, with fair surface and sheetage. Popular for ordinary printing and general utility.

Number 3 finish: Heavy pressure, with smooth surface and low sheetage. Used largely where better printing surface is required.

Number 4 finish: Heaviest pressure, with extra smooth and slick surface, dense body, and firmly compacted fibers. It has the lowest sheetage.

Rough; smooth: Where but two finishes are used, as in Gauge Lists 4 and 5, the relative terms 'rough' or 'smooth' designate lightweight or heavyweight board per caliper point.

428. Dimensions.—When stating the dimensions of a sheet, the width is given first, then the length, both in inches. *Width* is the measurement across the machine, *i.e.*, space between slitter knives; *length* is always the measurement in the direction of the grain, *i.e.*, space between knife cutoffs.

429. Bending.—A board is considered a **bender** if, when properly scored and folded, no break in the outer fibers is found.

430. Gauge Lists.—Gauge Lists 1 to 5 state in the first column the regular numbers (R.N.), or quantity of standard-sized sheets in a bundle weighing 50 lb. The following columns (except the last) give the corresponding calipers (decimals of an inch) of the board when made with the finish indicated. The kind or

variety of board to which the gauge list applies is given at the head of each table. The last column of each gauge list gives the weight per 1000 sq. ft. For Gauge Lists 1 to 5, this is found by multiplying 50 by 144 (= 7200) and dividing by the R.N.; for Gauge Lists 6 to 8, multiply the weight in the second column by 288 and divide by 1000. Thus, for Gauge List No. 6, caliper .024, 333 × 288 ÷ 1000 = 96 lb. per 1000 sq. ft.

431. To Find Weight per Ream (500) of Odd-Sized Sheets.—Using Gauge Lists 6, 7, and 8, select proper gauge list, find caliper in first column; opposite this in the second column is the weight (W') of 500 sheets 25 × 40; multiply this by the area ($d \times l$) of the odd-sized sheet, and divide by 1000; the result is the weight per ream (W). Expressed as a formula,

$$W = \frac{W'dl}{1000}$$

EXAMPLE.—What is the weight per ream of double manila wood-pulp filled board, 25 × 20 in., .028 caliper?

SOLUTION.—From Gauge List No. 8, $W' = 356$; hence,

$$W = \frac{356 \times 25 \times 20}{1000} = 178 \text{ lb.} \quad Ans.$$

SPECIFICATIONS

432. Trim.—Specifications must come within a minimum of 5 per cent of the maximum trim of the machine.

433. Test.—Unless otherwise specified, **test** shall mean minimum test, and shall be arrived at as follows: 1 sample, 12 in. square, shall be taken from the second or third ply of each roll. In each sample, there shall be made six tests on either Cady or Mullen jumbo tester (three each way), and not more than one of these tests may be below the specified test. All tests shall be made under relative humidity of from 35% to 65%, and the moisture content of the board must be from 6% to 8%. This test gives results in pounds per square inch.

434. Bending.—Unless otherwise specified, all test liner board shall be a bender (Art. **429**). To be a **bender**, a board must fold flat under pressure of the fingers, twice each way, forward and back, in the same crease, both with and across the grain, without breaking the surface fibers of the liner.

435. Waterproofing.—To be **waterproof,** a board must, when folded into tray form with the outer layer upward, and suspended, hold water for a period of two hours without moisture penetration, except where sand holes appear, and these must not be excessive.

436. Caliper.—A variation not to exceed .001 inch (one point) either way is allowable. Minimum calipers shall comply with carrier's published requirements.

437. Weight.—The average weight per one thousand square feet of rolls in a car shall not exceed the specified weight basis. A variation in weight of individual rolls is permitted, said variation to be not more than 5 per cent either way.

Weight shall be determined by taking one sample from each roll from the second or third ply, cutting the same to exact size, 12 × 12 in., and weighing same on an approved paper scale. In case of dispute, an additional sample shall be similarly taken from each roll and similarly weighed. All tests shall be made under relative humidity of from 35% to 65%, and the moisture content of the board must be from 6% to 8%.

438. Standard Grades.—The following are standard grades of test liner board when uncolored and waterproofed, or colored and waterproofed:

.016 caliper, 85 pounds minimum test;
.016 caliper, 100 pounds minimum test;
.023 caliper, 135 pounds minimum test;
.030 caliper, 135 pounds minimum test.

439. Basic Grade.—.016 caliper, 85 pounds minimum test, uncolored and waterproofed, shall be the basic grade of test liner board.

440. Extra Charges.—Extra charges shall be made for:

Rolls run 20 in. in width or narrower;
Rolls run 24 in. or less in diameter;
Tests higher than .016 caliper, 85 pounds;
Colored liner;
Less than carload lots;
Calipers less than .016 in. minimum;
Weights lighter than basic weights.

All extra charges shall not be less than the actual cost of such changes from the basic grade.

441. Disputes.—In case of disagreement, tests shall be made by a recognized laboratory, the finding of which will be final. The one in error shall bear cost of such laboratory test.

NO. 1 GAUGE LIST—NON-BENDING BOARDS

1. Plain straw board.
2. Plain chipboard.
3. Filled wood pulp.
4. Filled newsboard.
5. Single news vat-lined chip.
6. Single white vat-lined chip.

R.N. 50-lb. bdl.	Finish				Weight per M sq. ft.
	1	2	3	4	
Quan.	Inch	Inch	Inch	Inch	Lb.
35	.065	.061	.058	.052	206
40	.057	.054	.051	.046	180
45	.051	.048	.046	.041	160
50	.046	.043	.041	.037	144
55	.041	.038	.036	.033	131
60	.038	.035	.033	.030	120
65	.035	.032	.030	.028	111
70	.032	.030	.028	.026	103
75	.030	.028	.027	.024	96
80	.028	.026	.025	.023	90
85	.026	.024	.023	.022	85
90	.024	.022	.021	.020	80
95	.023	.021	.020	.018	76
100	.022	.020	.019	.017	72
110	.019	.018	.017	.016	65
120	.017	.016	.015	.014	60

NO. 2 GAUGE LIST—BENDING BOARDS

1. Single manila lined chip.
2. Bleached manila lined chip.
3. Double manila lined chip.
4. Colored box board chip back.
5. Bending chipboard.
6. Colored suit-box chip back.
7. Mist color suit-box chip back.
8. Cracker shell board.
9. Solid jute.
10. Any combination with chip, news, or pulp back.

R.N. 50-lb. bdl.	Finish				Weight per M sq. ft.
	1	2	3	4	
Quan.	Inch	Inch	Inch	Inch	Lb.
40	.052	.049	.047	.045	180
45	.047	.045	.042	.040	160
50	.042	.040	.038	.036	144
55	.038	.036	.034	.032	131
60	.035	.033	.031	.029	120
65	.031	.030	.028	.026	111
70	.029	.028	.026	.024	103
75	.027	.026	.024	.023	96
80	.025	.024	.023	.021	90
85	.023	.022	.021	.019	85
90	.021	.020	.019	.018	80
95	.020	.019	.018	.017	76
100	.019	.018	.017	.016	72
110	.017	.016	.015	.014	65
120	.016	.015	.014	.013	60

NO. 3 GAUGE LIST—SOLID NEWS AND SOLID WOOD PULP

R.N. 50-lb. bdl.	Finish				Weight per M sq. ft.
	1	2	3	4	
Quan.	Inch	Inch	Inch	Inch	Lb.
40	.061	.058	.053	.049	180
45	.054	.052	.048	.043	160
50	.049	.047	.043	.039	144
55	.045	.043	.039	.035	131
60	.041	.039	.036	.032	120
65	.038	.036	.033	.030	111
70	.035	.033	.031	.028	103
75	.032	.031	.029	.026	96
80	.030	.029	.027	.024	90
85	.028	.027	.025	.023	85
90	.027	.025	.023	.021	80
95	.025	.024	.022	.020	76
100	.023	.022	.021	.019	72
110	.021	.020	.019	.017	65
120	.019	.018	.017	.015	60

NO. 4 GAUGE LIST—PASTED CHIP

R.N. 50-lb. bdl.	Finish		Weight per M sq. ft.
	Rough	Smooth	
Quan.	Inch	Inch	Lb.
10	.216	.206	720
15	.144	.138	480
20	.108	.103	360
25	.086	.081	288
30	.070	.065	240
35	.060	.058	206

NO. 5 GAUGE LIST—PASTED SOLID NEWSBOARD

R.N. 50-lb. bdl.	Finish		Weight per M sq. ft.
	Rough	Smooth	
Quan.	Inch	Inch	Lb.
10	.233	.196	720
15	.156	.130	480
20	.117	.098	360
25	.094	.078	288
30	.078	.065	240
35	.066	.056	206

NO. 6 GAUGE LIST AND REAM WEIGHT TABLE—PATENT COATED AND SOLID MANILA BOARD

1. Patent coated, solid manila back.
2. Patent coated, news back.
3. Patent coated, news center, manila back.
4. Patent coated, chip back.
5. Patent coated, blue or color back.
6. Solid manila board.

Caliper of individual sheets	Weight per 500 sheets			Weight per M sq. ft.
	25 × 40 (1000 sq. in.)	24 × 36 (864 sq. in.)	28 × 44 (1232 sq. in.)	
Inch	Lb.	Lb.	Lb.	Lb.
.011	178	154	219	51
.012	194	168	239	56
.013	211	182	260	61
.014	219	189	270	63
.015	226	195	278	65
.016	241	208	297	69
.018	266	230	328	77
.020	284	245	350	82
.022	306	264	377	88
.024	333	288	410	96
.026	361	312	445	104
.028	389	336	479	112
.030	417	360	514	120
.032	444	384	547	128
.034	472	408	582	136
.040	556	480	685	160

NO. 7 GAUGE LIST AND REAM WEIGHT TABLE—PATENT COATED TWO SIDES

Caliper of individual sheets	Weight per 500 sheets			Weight per M sq. ft.
	25 × 40 (1000 sq. in.)	24 × 36 (864 sq. in.)	28 × 44 (1232 sq. in.)	
Inch	Lb.	Lb.	Lb.	Lb.
.011	184	159	227	53
.012	201	174	248	58
.013	218	188	269	63
.014	227	196	280	65
.015	234	202	288	67
.016	250	216	308	72
.018	277	239	341	80
.020	295	255	363	85
.022	318	275	392	92
.024	347	300	428	100
.026	375	324	462	108
.028	404	349	498	116
.030	433	374	533	125

NO. 8 GAUGE LIST AND REAM WEIGHT TABLE—DOUBLE MANILA WOOD-PULP FILLED BOARD

Caliper of individual sheets	Weight per 500 sheets			Weight per M sq. ft.
	25 × 40 (1000 sq. in.)	24 × 36 (864 sq. in.)	28 × 44 (1232 sq. in.)	
Inch	Lb.	Lb.	Lb.	Lb.
.015	208	180	256	60
.016	222	192	273	64
.018	249	216	307	72
.020	265	230	327	77
.022	283	244	348	81
.024	305	264	376	88
.026	331	286	408	95
.028	356	308	439	103
.030	364	315	449	105

NOTE.—The weights per 1000 square feet listed in this and Gauge Lists 10 and 11 are those now in effect, but are subject to such changes as may develop from changes in Rule 41 of the Consolidated Freight Classification.

NO. 9 GAUGE LIST—TEST CONTAINER BOARDS

Double fiber board, made with two jute liners and two or more ply of chip, sized on one side, colored on one or both sides, bending.

Caliper	Minimum test	Weight per 1000 sq. ft.
Inch		Lb.
.120	300	440
.100	275	375
.080	200	305
.060	175	235

NO. 10 GAUGE LIST—TEST BOARDS

Grade	Caliper	Weight per 1000 sq. ft.
	Inch	Lb.
Jute liner....................	.016	64
Jute liner....................	.023	92
Jute liner....................	.030	120

NO. 11 GAUGE LIST—NON-TEST BOARDS

Grade	Caliper	Weight per 1000 sq. ft.
	Inch	Lb.
Chipboard..................	.009	28
Chipboard..................	.016	60
Straw board................	.009	34
Chestnut....................	.009	34
Pinewood....................	.009	29

PAPERMAKING MACHINES

(PART 5)

EXAMINATION QUESTIONS

1. What is the essential difference between the cylinder paper machine and the Fourdrinier paper machine?

2. For what papers is the cylinder machine especially adapted?

3. Explain the formation of the paper on the cylinder machine.

4. Why is it necessary to have a separate screen and regulating box for each mold?

5. What precautions should be taken with steam joints on the dryers of a cylinder machine?

6. (*a*) Why is it necessary to squeeze a heavy paper gradually? (*b*) How is this accomplished?

7. How is stock kept from leaking into the cylinder mold?

8. Compare the cylinder machine with the Fourdrinier machine with respect: (*a*) to the relative strength of the paper in the machine direction and cross direction; (*b*) to consumption of clothing; (*c*) to speed.

9. (*a*) Do you understand the differential gear? (*b*) What is its purpose?

10. What is the distinctive feature of the Harper machine?

11. (*a*) What is meant by M. G. paper? (*b*) creped paper? (*c*) double-faced paper? (*d*) State briefly how each kind is made.

12. How much salable paper is made in 1 hour by a machine running 900 ft. per min., making 35-lb. newsprint 24 × 36—500, the trimmed width being 146 in.? When making the calculation, use the formulas of Art. **409**. *Ans.* 7665 lb. per hr.

13. If the machine in Question 13 is required to make 32-pound newsprint (24 × 36—500) with the same deckle (width of paper) and the production is to be the same as before, at what speed must the machine run? *Ans.* 984 ft. per min.

14. Explain a method for determining the speed of a paper machine.

15. An order is received for 75,000 kilograms of book paper 63 × 96—500, 18 kg./500. What is (*a*) the weight of a ream 25 × 38—500? (*b*) the weight in grams per square meter? (*c*) How many reams will fill the order?

Ans. (*a*) 40.21 lb.
(*b*) 59.5 g./m.^{2}
(*c*) 4167 reams.

16. A cylinder machine is making board 16 × 24—200. The sheet width is 126 in. and the speed is 126 ft. per min.; what is the production in pounds per hour? *Ans.* 7088 lb. per hr.

17. What is the production in pounds per hour of a machine making 18-ounce hanging paper at a speed of 390 feet per minute, the paper being the wide roll and measuring 120 in. on the reel? *Ans.* 5850 lb. per hr.

18. (*a*) What three types of machine are used in forming insulating boards? (*b*) Describe two types of dryer section used for these boards.

19. What measures are taken to obtain the greatest efficiency from the dryers of a cylinder machine?

20. Referring to boards, what is meant by: (*a*) count? (*b*) regular number? (*c*) caliper? (*d*) What is the regular number for double manila lined chip, bending, .019 caliper, 20 × 35?

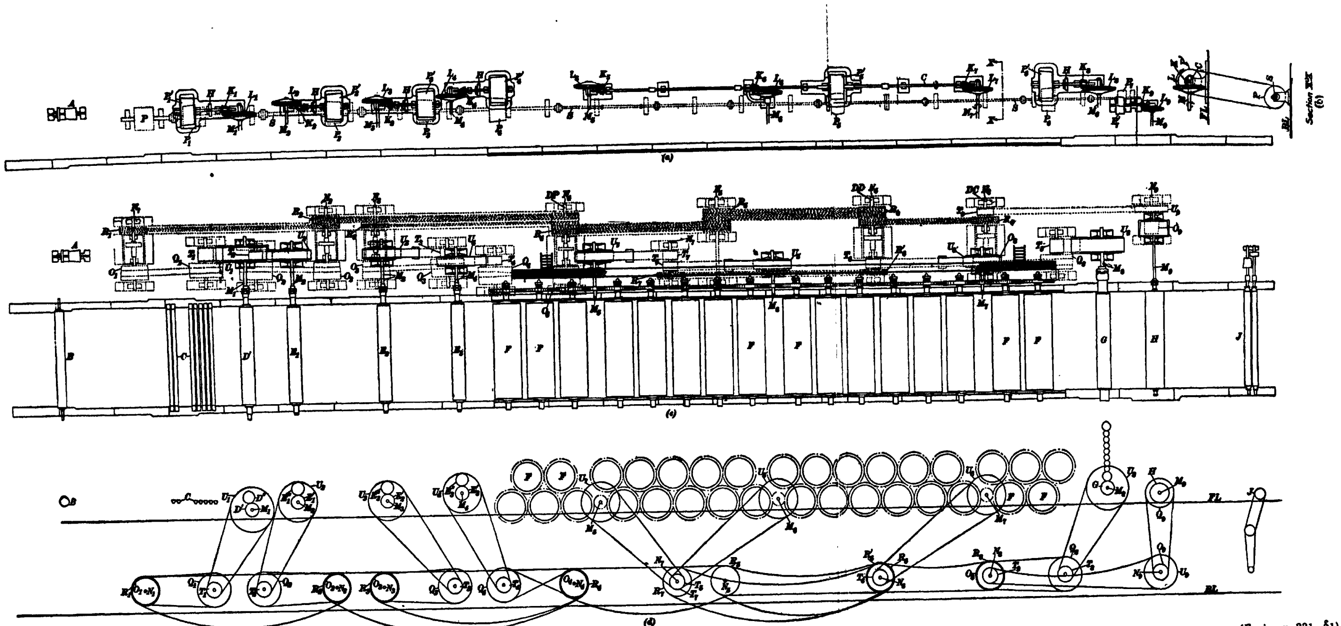


FIG. 134.

(Facing p. 331, §1)

SECTION 1

PAPERMAKING MACHINES

(PART 6)

NOTE.—The revision of Part 6 was compiled by the Editor, with generous assistance from manufacturers of papermaking machines and electric drives.

THE PAPER-MACHINE DRIVE

BASIC PRINCIPLES

442. General Statement.—In Parts 1–5 of this subject, Papermaking Machines, the various types of papermaking machines have been discussed and the functions of the various parts have been explained. Attention will now be given to the discussion of the different methods of driving a papermaking machine.

The basic principles of the paper-machine drive will become clear after a careful study of Fig. 134 and the accompanying detailed description of this typical book-paper machine and the two types of drives there shown. This illustration has been so drawn as to exhibit two methods of driving the machine: views (*a*) and (*b*) represent what is called a **variable-speed line-shaft drive,** and views (*c*) and (*d*) represent what is called a **rope drive**; and either form of drive may be used on this machine. The machine itself is shown (in diagrammatic form) for the purpose of emphasizing the features of the drives. The parts indicated are: the shake head *A*, breast roll *B*, suction boxes *C*, couch press *D*, wet presses E_1, E_2, E_3, dryers *F*, calenders *G*, reel *H*, and winder *J*. Also, the machine-room floor is indicated by *FL*, the basement level by *BL*, a friction clutch by *FC*, drives for presses by *DP*, drive for dryers by *DD*, and drive for calenders by *DC*. Dotted lines indicate equipment in the basement. It will be noticed that *C* also represents the countershaft for the dryer drives. While one machine will differ from another in certain

respects, the essential parts of a typical machine are here shown; furthermore, the principles now to be explained will apply to all types of machines.

443. Necessity for Varying Speeds.—The speed of all *parts*, *i.e.*, **sections,** of the paper machine, from the couch press *D* (which controls the speed of the wire) to the reels *H*, Fig. 134, must be capable of simultaneous variation, to allow for difference in thickness, character, and quantity of the paper to be made; further, the speed of each section must admit of variation relative to the speed of other sections of the machine, *i.e.*, it must have independent, individual control. This object is accomplished by having as a medium of power transmission a line-shaft or rope drive, the speed of which can be changed throughout, and which drives individual sections in such a manner that the speed of each section may be altered without affecting the speeds of any of the others. Fig. 134 shows two arrangements of this kind, a rope drive being indicated at (*c*) and (*d*), and a variable-speed line-shaft drive at (*a*) and (*b*); the latter would more properly be called an adjustable-speed line-shaft drive, usually referred to as the Marshall drive, and will be discussed fully later.

444. The Constant-Speed Line.—Other parts of the machine, including stuff pump, suction pump, white-water (fan) pump, screens (not shown in Fig. 134), and shake head *A*, are driven at constant speed from a **constant-speed shaft** or by independent motors. The winder *J* should also be driven independently of the machine, because it is not running constantly; hence, if it were connected directly to the machine drive, it would tend to cause variations in the weight of the paper when this load is thrown on the variable-speed line. A satisfactory way to drive the winder is to use a separate motor. All these parts must run at a speed that will suffice to take care of the machine at its maximum output. Pumps that keep the shower pipes supplied with water at the proper pressure are also usually driven from the constant-speed shaft, or by individual motors.

The constant-speed shaft is generally driven by a belt from a motor, engine, or a shaft that is driven by a water wheel or steam turbine and the usual speed is 200–250 r.p.m. The various pumps, etc., are connected to the constant-speed shaft by belts and pulleys. In practice, the constant-speed shaft generally uses

about 24% of the total power required to drive both the constant-speed and variable-speed shafts; hence, about 3 times as much power is required to drive the variable-speed shaft as is required to drive the constant-speed shaft.

445. The Variable-Speed Shaft.—Considering the variable-speed (adjustable-speed) line, a drive must be installed that will be capable of, first, a wide speed range (up to 8 or 10 to 1); second, the shafts driving the different sections of the paper machine itself must run at such relative speeds as not to stretch the paper or allow any slack between the sections, as the paper goes through the machine. This problem would be simple if the paper itself did not get longer (by pressing) at one place and shorter (by drying) at another place; or if it could be accurately foretold exactly how much longer or shorter it would become. Unfortunately, no two kinds of paper are stretched the same amount through the same machine; in fact, no two similar machines will stretch the same kind of paper the same amount, even when operated by the same machine tender and crew. Finally, no two machine tenders will stretch the same paper exactly the same way or amount through any one machine. A change in the character of the stuff may cause a variation in stretch or shrinkage during a run.

446. Stretch of Paper between Rolls.—In general, paper is pulled or stretched to such an extent that in its passage from the couch roll to the calenders it is 5% to 9% longer at the reel than it was at the couch roll. This stretch must be compensated for by increasing the surface speed of the succeeding machine parts. For instance, the first-press roll drive should be so designed that, on the average, the lower press roll will have 3.5% greater surface speed than the lower couch roll. The student should take note of the term *surface speed;* this is, of course, in this case, the same as the paper speed.

As an example, suppose the couch roll is 20 in. in diameter and the press roll is 18 in. in diameter; then, if the surface speed of both rolls is the same, the r.p.m. of the press roll will be $\frac{20}{18} = \frac{10}{9}$ times the r.p.m. of the couch roll. But the surface speed of the press roll must be 3.5% greater than that of the couch roll; hence, the r.p.m. of the press roll must be $1.035 \times \frac{10}{9} = 1.15$ times the r.p.m. of the couch roll. In other words, with these

diameters, for every 100 revolutions of the couch roll, the press roll must make 115 revolutions.

In a manner similar to that just described, the respective ratios of the shaft speeds of all the different sections of the machine can be approximately calculated, and the results will be close enough to come within the range of control of the cone pulleys (to be described later).

447. Relative Surface Speeds of Different Sections.—The relative surface speeds of the rolls for the different sections as compared with the surface speed of the couch roll are:

Couch	1st Press	Last Press	Dryers and Calenders
100	103.5	105.4	106.0

When a suction roll is used instead of a pair of pressure rolls, the paper does not stretch so much on its way to the first press, and it is necessary to change the above values somewhat, the following being used instead:

Couch	1st Press	Last Press	Dryers and Calenders
100	101.3	104.6	105.6

From the foregoing, it will be perceived that extreme care is needed in the design of the drive for the variable-speed line of the paper machine. There are several different types of drives in use, the most typical of which will now be described.

TYPES OF MECHANICAL DRIVES

THE MARSHALL DRIVE

448. General Description.—The type of machine drive that is most widely used is that known as the **Marshall drive,** also called the **Marshall train.** This drive is clearly shown in views (*a*) and (*b*) of Fig. 134. The variable-speed line shaft S is here placed in the basement, as is customary—see view (*b*)—but when basement room is lacking, it may be placed overhead. The shaft S carries the cone pulleys P_1 to P_7, inclusive, which are belted to pulleys P_1' to P_7', and through these and the bevel gears, the power is transmitted from shaft S to the couch roll, the three press rolls, the dryers, the calender stack, and the reel. The paper is reversed on the third press; consequently, the drive on this press

is made with the position of the bevel gears K_4L_4 reversed, as compared with the other bevel gears. The reel at the end of the machine may be driven by a slipping belt, in a manner similar to that described in Fig. 104.

449. Speed Changers.—Until the introduction of the variable-speed engine and the variable-speed motor, paper machines (including both constant-speed and variable-speed shafts) were driven by steam engines, motors, or water wheels at practically constant speed, and some type of speed changer was used between the prime mover and the variable-speed shaft. A very early arrangement was a pair of change gears; and by using 16 different gears, in proper combination, a certain machine was rated to run at the following speeds: 23, 26, 28, 31, 39, 43, 47, 58, 78, 101, 125, 160, 180, 200, 225, and 254 ft. per min.

450. The Cone Pulleys.—With the arrangement just described, the intervals between speeds were too great at the top of the scale, so cone pulleys were introduced. Such an arrangement is represented in Fig. 135, which shows the flywheel or pulley A of the engine, or the pulley of a constant-speed motor, turbine, or water wheel, belted to the pulley B on a shaft C. On shaft C is a step pulley D, which may have 2 or 3 steps, in order that the corresponding step pulley E and the cone pulley F, attached to the same shaft as E, may be given 2 or 3 different speeds. The speed interval between the step-pulley speeds is uniform, and is equal to the range covered by the pair of cone pulleys F and G. The cone pulleys are identical, except that they point in opposite directions, and the belt that connects them is shifted from one end to the other, or to any point between the ends, by means of the belt-shifting device H. The belt runs between a couple of iron loops at the ends of a casting, through the center of which runs a long screw, the turning of which carries the belt from end to end of the cones. Whether or not the step pulleys are required depends upon the range of speeds demanded of the machine. Cone pulley G is connected to the variable-speed shaft S, Fig. 135, by a belt that connects pulleys J and K.

451. Other Types of Speed Changers.—There are several other types of speed changers on the market. In one make, two pulleys are so constructed as to have a variable diameter. This is effected by using two disks for each pulley and having the

faces beveled instead of parallel to the axis of the shaft; the bevels face each other, so as to make a V-shaped opening between the disks. The size of this opening is varied by shifting one of the disks along the shaft. The under side of the belt that runs between these pulleys has V-shaped wooden blocks firmly attached to it, the angle of the V being the same as that of the opening

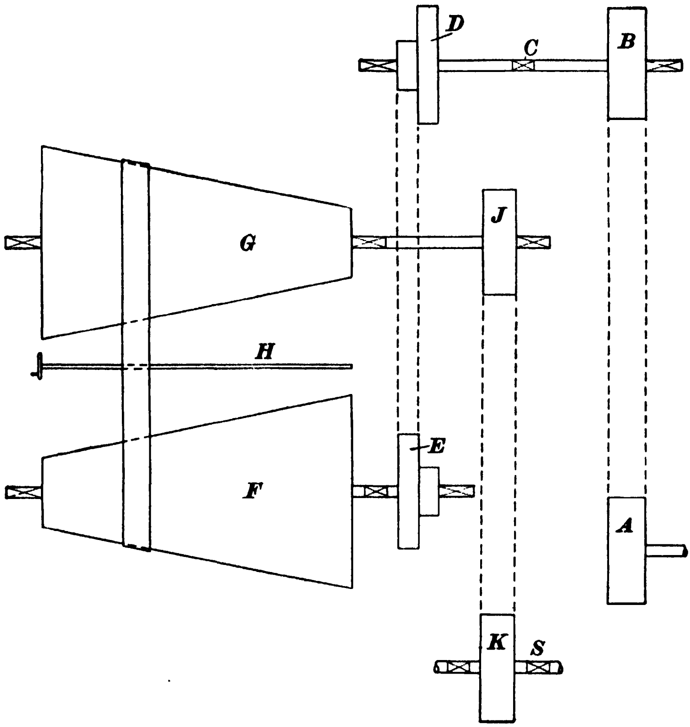


FIG. 135.

between the disks that form the pulley. When the disks are close together, the distance between the axis of the shaft and the belt (the radius of the pulley) will be a maximum; and when they are farthest apart, the radius will be a minimum. Evidently, the radius of one pulley will be a maximum when the other is a minimum, and a considerable range of speed can be obtained smoothly with this device.

Variable-speed motors and steam engines have largely replaced the cumbersome cone pulleys; they save both space and power.

The engine may be belted to the variable-speed shaft, but it is frequently direct-connected to it; and when this is done, it is advisable, for safety, to use a flexible coupling. Variable-speed motors are used when electricity is available, and also as speed changers when electricity is generated by steam power. The use of individual motors on each section of the machine will be discussed later.

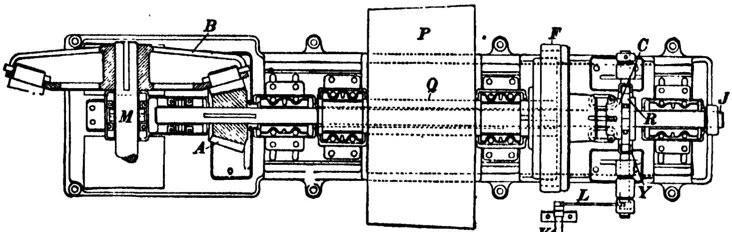
It should be noted that some machines are designed to be operated at constant speed, and they are equipped with the proper kind of prime mover.

452. The Prime Mover.—It may here be mentioned, but the matter will not now be discussed, that there is some divergence of opinion as to whether it is better to use steam at boiler pressure for drying the paper or to use it for power purposes first and then dry the paper by exhaust steam from the engine or turbine. Careful study should be accorded to the problem of 'heat balance' when selecting a prime mover for the paper machine, in which connection, the steam requirements for the entire mill must be considered. Any type of prime mover may be used to operate any of the types of mechanical drives herein described.

453. Variable-Speed Line Connections.—Regardless of the type of variable-speed line used, it is necessary to connect it to the machine by means of belts and clutches; also, means must be provided for altering the speeds of individual parts, and for starting and stopping them at will. At the same time, it is necessary in most cases to change the direction of the drive, from a line shaft parallel to the machine to that of the intake shafts at right angles to the machine, and to reduce the speed. An **intake shaft** is one by which power is transmitted to a machine section, as M_1, M_2, . . . M_9, Fig. 134, each of which is at right angles to the variable-speed shaft S and to the machine. The change of speed and of direction is accomplished simultaneously, the direction being changed by the bevel gears, and small changes in speed by the cone pulleys; the starting and stopping is effected by some form of clutch.

454. The Quill Drive.—In Fig. 136 is shown, in plan (*a*) and elevation (*b*), a gear stand and **quill drive**, so called because the pulley P is fastened to a hollow shaft, or 'quill,' which turns

freely on the jack shaft passing through it. Here A is the small bevel gear, driving gear, or pinion; B is the large bevel gear, or follower, on the intake shaft M; and P is the pulley that drives the jack shaft J; F is a friction clutch, one half of which, F_2, is clamped to the hub of pulley P, or the quill Q to which this pulley is keyed, and the other half, F_1, is keyed to the jack shaft J, along which it can slide. When the clutch lever on the front side of the machine is thrown in, the lever rod K, links L, and yoke Y push ring R and collar C to the left, thus forcing clutch



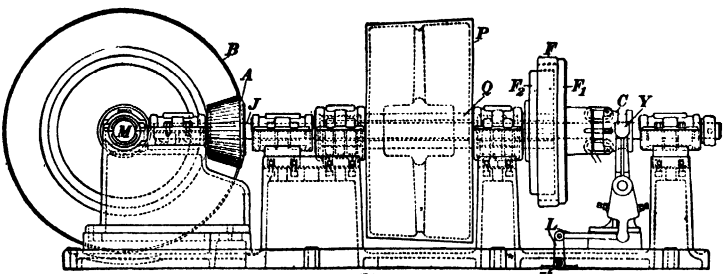


FIG. 136.

face F_1 against face F_2. The half face F_1 and collar C are connected to each other by bolts, and ring R turns freely in collar C. The rubbing surfaces of the two halves of the clutch slide on each other at first, until the speed in revolutions per minute has become the same as that of the pulley P. If the clutch did not slip at first, the belt driving the pulley would either slip or break. If a direct-connected motor were used, the motor would simply draw from the line the extra power needed to start up the machine section and give it the required acceleration.

The character and material of the rubbing surfaces of the clutch vary with different makes, and the surfaces may be conical, spherical, or flat. The wearing surfaces should be lined, wood or leather being a good material for this purpose. The lining should be watched, and it should be replaced before being actually worn out. While this is a millwright's job, the machine tender should study his clutches and understand how to line them in cases of emergency. Friction clutches on fast machines usually have *no* lining, iron on iron surfaces being used.

In this case, the pulley *P* revolves around the jack shaft *J* when the clutch is not in; it is what is generally called a *loose pulley*. When the clutch is thrown in, the revolving motion of the belt-driven loose pulley *P* is transmitted to the jack shaft *J*, and through it, to the small driving bevel gear *A*.

To the ordinary observer, there is no difference between a quill drive and a loose-pulley drive; in either case, the pulley revolves all the time, whether the gears are turning or not. The loose-pulley drive has the clutch on the hub of the pulley, the whole clutch being practically contained in the pulley; this type is more compact than the quill drive. Care should be taken to keep the drives (either kind) properly lubricated; the quill drive, especially, should be kept well oiled. The quill drive is more expensive, but it wears better than the loose-pulley type of drive. In quill drives, it is very essential to keep the bearings in perfect condition and have them bolted to the base with finished bolts, fitting in tight holes.

455. The Friction Clutches.—The friction clutches are generally so placed on the jack shaft *J*, Fig. 136, as to be handy to operate by the machine tender. This is the most convenient position, because, when the clutch is out, the gears are still. If there were no gears, as is sometimes the case, as in a rope drive, the place for the clutch, to give it 'pickup' power, would be on the slow-speed intake shaft, directly on the machine part (section).

There is probably no mechanical detail of the paper machine that is less understood, whose treatment is more likely to be severe, than the friction clutch; and this is largely due to the lack of knowledge of their own product that is shown by manufacturers of friction clutches, as revealed in their tables of horsepower and capacity. The reader will do well to note particularly

the following: First, when in and the load has been picked up, a friction clutch will transmit power in proportion to its speed; for instance, under these conditions, a friction clutch that transmits 30 hp. at 100 r.p.m. will transmit 60 hp. at 200 r.p.m., and 90 hp. at 300 r.p.m. Second, a friction clutch will not pick up a load from rest at more than two-thirds of the rating at 100 r.p.m. that is usually given in the manufacturer's table; and it will pick up a still smaller proportion at higher speeds. A belt acts in the same manner as a friction clutch; it will slip if an attempt be made to put it on at high speed and under a heavy load; it must be started slowly and pick up gradually, if slipping is to be avoided, though it will carry the load when everything is moving at the proper speed. On a paper machine, the friction clutch is thrown in, and it tries to pick up the load; luckily, however, the belt on the driven pulley slips, which thus gives the clutch a chance. On a slow-speed machine, friction-clutch troubles are slight; but on a high-speed machine, the friction clutch that is installed according to the horsepower listed by the manufacturer will usually be too small, and it will cause endless trouble. The reason for the comparatively low pickup power of a friction clutch is because of the very great increase in power required to start (*i.e.*, accelerate) the load. When a locomotive starts to pull a heavy train, it starts very slowly, gradually increasing its speed until the required limit of speed is reached. Suppose, now, that the locomotive could be raised so that the drivers just cleared the rails, but that the drivers were turning at the required speed the train was to run. If the locomotive were allowed to drop on the rails very suddenly, the case would be exactly the same as when a friction clutch is thrown in. An enormous load would suddenly be placed on the engine of the locomotive, there would not be enough friction to start the train, and the drivers would simply whirl around, slipping on the rails. But if the engine were to continue to run, the train would gradually start, and the amount of slipping would become less and less, until the train were finally in full motion. This is exactly what happens with a friction clutch; the loose pulley is running all the time, and there must be more or less slipping before it picks up the load. The more powerful the clutch, the sooner it will pick up; and the faster the speed the longer it takes to pick up. Hence, throw the clutch in slowly. On heavy loads, give the lever a jerk, then

release it, quickly repeating this several times, until the machine section is in full motion.

456. The Cone Pulley.—The cone pulley F, Fig. 135, is connected by a belt to its counterpart G, which slopes in the opposite direction, on the variable-speed shaft. A narrow, heavy belt is used; this reduces the width of the pulley, and the belt is less damaged by the belt shifter. Small changes of speed of a section, which are made necessary by changes in the 'draw,' are effected by moving the belt; usually a shift of $\frac{1}{4}$ to $\frac{1}{2}$ inch is sufficient to provide the required change in speed. This use of cone pulleys is the basis of the Marshall drive.

An important point to remember in connection with the drive of a paper machine is to make the pulleys, belts, and ropes of ample size; the extra cost of large belts and ropes is easily compensated for by the saving in cost of repairs, replacements, and upkeep.

457. Details of Marshall Drive.—Referring to Fig. 134, (*a*) is a top view and (*b*) is an end view at XX of the variable-speed shaft and gearing for a Marshall drive. The line shaft (variable-speed shaft) S is shown dotted; it is usually in the basement, but may be placed overhead in the machine room, and is driven from a suitable source of power, the prime mover. The cone pulleys P_1 to P_9 on this shaft are belted to corresponding cone pulleys P_1' to P_9' on the machine-room floor, *i.e.*, situated near the machine-room floor. Each of these latter pulleys is mounted on a jack shaft (countershaft) J, Fig. 136, which carries also a bevel pinion, as K_1 to K_9, which drives the large bevel gear, as L_1 to L_9. The large bevel gears are mounted on the intake shafts M_1 to M_9 that lead to the various sections, to which they are connected by clutches, as shown in view (*c*). Note that press E_3 turns in a direction opposite to that of the other presses; this reversal is accomplished by having the large bevel gear L_4 mesh with the upcoming side of the pinion K_4 instead of the downgoing side, as in K_2 and K_3. The couch-roll gear is not reversed. Observe also that there are three intake shafts to the dryers; some machines have only two. Pulleys P_5 and P_5' are not cone pulleys, strictly speaking, as the faces do not slope; these pulleys drive the dryers, and the speeds of the other sections are regulated rela-

tively to the speed of the dryers. The relative sizes of these two pulleys (the ratio of their diameters) vary according to sizes of the rolls they drive. It will be shown later that the direction of rotation may also be reversed by using a crossed belt on the cone pulleys.

458. Enclosed-Type Drives.—Although many papermaking machines are operating with the older types of Marshall drives that have mortise bevel gears carried on various arrangements of stands and mountings, as previously described, these types are gradually giving away to new drives, which use either spiral (helical) bevel or hypoid gears, and which run in an oil bath continuously. The gear casing and stands are mounted on a rigid base, so the whole unit will remain level and in line.

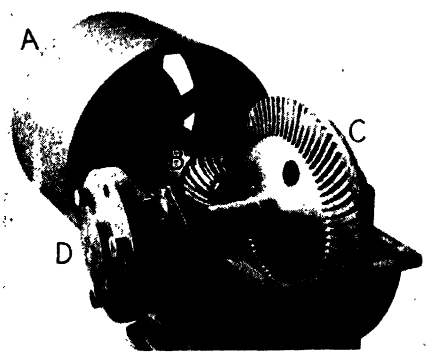


FIG. 137*a*.

A **bevel-gear** assembly is shown in Fig. 137*a*, in which *A* is the cone pulley receiving power from the main-line shaft; *B* and *C* are the driving pinion and crown gear, respectively, *D* is the drive intake connection to the machine or section to be driven.

A **hypoid-gear** assembly is shown in Fig. 137*b*. It is seen that the hypoid-pinion shaft, which is connected by the flange through a belt-driven pulley, or otherwise, to the main-line shaft, passes over the crown-gear shaft, which is connected to the intake shaft of the machine or section to be driven.

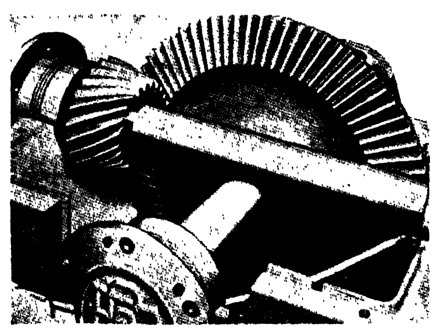


FIG. 137*b*.

The shafts are carried in antifriction bearings, and the usual taper (cone) floor pulley, with which either a friction clutch or cutoff couplings are used. A simple-geared oil pump is driven

from the hypoid-gear shaft. The oil is then carried in copper pipes to all the bearings, and the surplus oil is lead back to the gear-casing reservoir. In some cases, the oil may be lifted up on the gear by centrifugal force, caught in a small reservoir, and then flow by gravity to the various bearings. But should the gear-rim speed be too low, it will not pick up sufficient oil properly to lubricate the bearings. The positive oil pump is reliable, and it is much better to depend on it than on the gear rim to pick up the oil.

The gears and pinions are steel castings, or forgings of various steel alloys, and have high tensile strength and toughness. This allows the use of gears of narrower face and finer pitch for the same strength than is possible with the cast-iron straight bevel gears formerly used. With straight bevel gears, the whole load comes on one tooth at a time; but with spiral bevel or hypoid gears, several teeth are in contact at the same time, giving much smoother and more nearly continuous action.

With spiral bevel gears, the center lines of the gear shaft and pinion shaft intersect, *i.e.*, they lie in one plane, the same as with ordinary straight bevel gears. With *hypoid gears*, though the center line of the pinion shaft is at right angles to that of the gear shaft, it passes over or under the center line of this shaft.

Spiral bevel and hypoid gears are designed for transmitting power between shafts at practically any angle. They should be used for all high-speed drives (above 800 ft. per min.) where smooth and quiet operation, together with minimum size, are required. The continuous pitch-line contact of spiral bevel and hypoid gears makes it feasible to obtain superior performance with a smaller number of teeth in the pinion than is possible with straight bevels.

In some cases, where large gear ratios are required, a pair of spur gears are also enclosed in the gear case, making a compound-gear combination. The relative *size* of a mortise bevel gear and pinion to transmit the same horsepower as a pair of all-steel spiral bevel gears is about 2 to 1. The spiral bevel gear may be fitted with a magnetic friction clutch instead of the usual mechanical friction clutch. A cutoff coupling can be provided between the gear unit and the cone pulley.

When the line shafting is located in the mill basement, a removable steel belt guard covers the cone pulley and friction clutch,

thus eliminating the danger of operatives getting caught in the belt. In some cases on large, fast-running machines, the cone belt shifters are operated by electric motors having push-button control.

459. Spiral Bevel-Spur-Gear Drive.—In place of the conventional spur gears of large diameter for driving the dryer gears, the spiral bevel-spur-gear drive has been developed; this provides totally enclosed gears that run in oil on the back side of the machine, leaving the back side mostly open, largely eliminating noise through the use of low pitch-line velocities and accurately alined spiral bevel gears. Employing small-diameter spur gears on the dryer journal, which mesh with horizontal pinions, makes it possible to use conventional plain bearings on the dryer journals without danger of meshing trouble. The numerous identical spiral bevel-gear units, on the gear shaft of which the spur pinion is located, permit the connecting together of the dryers through flexible couplings, with only the power required for one dryer roll being transmitted through each individual gear unit. Obviously, either mechanical or electrical sectional drives for the machine can be used.

An application of bevel-gear trains to a board machine, with dryers arranged in vertical groups, is shown in Fig. 138. In this case, the driving motors M will run at 1145 r.p.m. for a paper speed of 1200 ft. per min. The other reference letters denote: G, 1:1 spiral bevel gears; B, 3:1 spiral bevel gears; S, 4:1 spur gears; D, pinion shafts; O, offset pinion shafts driven by bevel gears from pinion shaft D; C, dryers. A chain drive on a dryer section is shown in Fig. 82.

460. Reversing Gear on Calender Drive.—On machines making box board, where a wad or plug is liable to stall the calender rolls, a differential geared mechanism is employed to provide a reverse drive. When the calenders are running, the friction clutch is engaged and the cone-pulley differential (planetary) gearing[1] and shaft all revolve together. To back up to dislodge a wad in the stack, the clutch is thrown out, leaving the pulley running free. The planetary train revolves with the pulley, the shaft being stationary because the calender has stopped. A

[1] This mechanism is fully explained and illustrated in Art. **503**.

brake is now applied to stop the planetary ring-gear housing. This causes the planetary pinions slowly to reverse the direction of the spider on which they are mounted, and with it the calender drive shaft, to which the spider is keyed, and the wad is released.

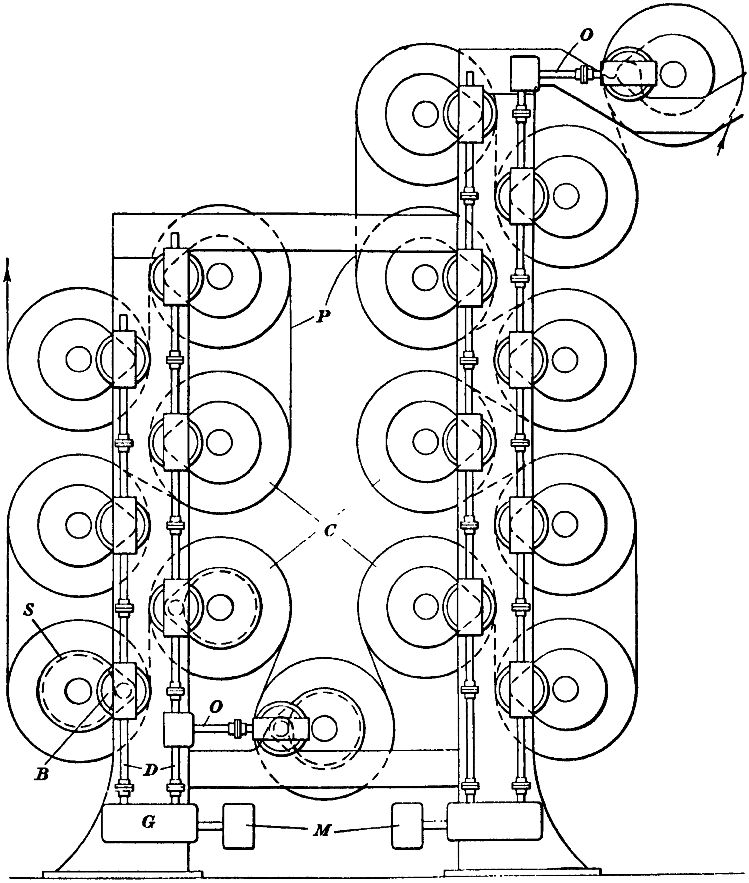


Fig. 138.

Caution should be used not to apply the brake with the clutch in, or engaged, or to throw in the clutch when the brake is on.

A small high-torque, alternating-current, reversing, calender motor drive, with powerful torque and automatic interlocks, both

mechanical and electrical, may also be used for reversing the stack to back out wads, with no possibility of throwing in the reverse while the calender is driven forward, or of starting up the stack forward while the reverse drive is engaged.

THE ROPE DRIVE

461. Description of Rope Drive.—What is called a **rope drive,** which is a variation of the Marshall drive, is shown at (*c*) and (*d*), Fig. 134. The rope drive proper is in the basement, as shown in view (*d*). Power from the prime mover (under the machine but not shown) enters the machine through shaft N_5, and it is transmitted in both directions from rope sheave R_5 on this shaft. Going to the left, sheave R_5 drives sheave R_4, on shaft N_4; sheave R_4 drives sheaves R_3 and R_2, on shafts N_3 and N_2, and sheave R_2 drives sheave R_1, on shaft N_1. Going to the right, sheave R_5 drives sheave R_6, on shaft N_6; sheave R_6 drives sheave R_8, on shaft N_8. On shaft N_6 is another rope sheave R_6', which drives sheave R_7, on shaft N_7. These sheaves, with their ropes, constitute the rope drive. Shafts N_1, N_2, N_3, N_4, N_8, and N_9 carry the cone pulleys O_1, O_2, O_3, O_4, O_8, and O_9, which are belted to the corresponding cone pulleys Q_1, Q_2, Q_3, Q_4, Q_8, and Q_9, on the same shafts that carry pulleys T_1, T_2, T_3, T_4, and T_8. Plain pulleys T_5, T_6, and T_7 are fastened direct to shafts N_5, N_6, and N_7, because the dryers are not driven through cone pulleys, for the reason previously stated. All the sheaves and pulleys so far mentioned (except cone pulley Q_9) are located in the basement, as shown in view (*d*). Each pulley T is belted to a pulley U, on an intake shaft M (except U_9). Thus, T_1 is belted to U_1, which, in turn, drives M_1 and couch roll D'; T_2 is belted to U_2, which, in turn, drives M_2 and the first-press roll E_1; etc. Note that a crossed belt connects O_4 to Q_4, to reverse the direction of the third-press roll E_3.

462. Discussion of Rope Drive.—The rope drive is very efficient; but care must be taken to insure that the belts are wide enough and have sufficient bearing contact on the face of the small pulleys T. Tightener pulleys may be used on these belts, to effect an easy start of the machine. With this type of drive, the different sections can be started up by using a friction clutch,

or by so laying out the drive that the belts are vertical; then, when the belt is loose, the section is still, and it may be started by throwing an idler (tightener) pulley against the belt. This is done by turning a hand wheel, on the machine-room floor, which operates a shaft and worm gear. This latter arrangement is a feature of the Lloyd-Hutchinson, or Walmsley, drive.

Note that T_9, Fig. 134, is a belt pulley on jack shaft N_8; it drives U_9, on shaft N_9, which also carries the cone pulley O_9. The cone pulley Q_9, which is driven by O_9, is the only cone pulley on the machine-room floor, all the others being in the basement. Evidently, there is some range of choice in the matter of locating the cone pulleys; the main point to remember is that once any particular section has been selected as the one that is to run at what may be termed the 'master' speed, all the others must be provided with independent regulating devices.

463. Ropes and Sheaves.—Practical experience has given evidence of the superiority of cotton ropes for paper-machine drives. Cotton ropes of good make will last indefinitely; they will outlast the harsher fibered manila ropes in the ratio of at least 2:1.

An important feature in the design of rope drives is the angle made by the faces of the grooves in the sheaves; the pinch of these on the rope is the principal factor in preventing slip. The rope should not lie on the curved bottom of the groove. The most efficient angle of groove, the angle included by the sides of the groove, is 45° for the English system and 60° for the American system of drive.

Another important feature of the design of sheaves is that they must not be too small in diameter; the diameter of a sheave should not be less than 40 times the diameter of the rope.

Since the strength of a rope varies as the square of the diameter, approximately, the advantage of using a large rope is evident; but the rope must not be too large, since its flexibility decreases as the diameter increases. A large factor of safety, at least 10, should be used in determining the size of the rope; this insures against too rapid wear, as well as against breaking.

The grooves must be polished smooth, to prolong the life of the rope; and the sheaves must be correctly alined, to prevent the wearing of the ropes as they fall into the grooves.

464. English and American Systems.—There are two distinct systems of rope drive—the English and the American. In the English system, a separate rope is used for each loop, there being as many ropes as there are grooves used. In the American system, a single long rope only is used; it starts from the first groove in one pulley (sheave), passes around the corresponding groove in the second pulley, then back to the second groove of the first pulley, and around the second groove of the second pulley, and so on, until the required number of grooves have been filled. The free end of the rope then passes over a big, single-groove, cross-over pulley, which is set diagonally in a carriage, so as to bring the free end to groove number 1 in the first pulley, where it is spliced to the other free end. The carriage slides on ways, which thus enables it to act as a tightener, and counterweights automatically take up the slack that is caused by stretching. After a time, the slack becomes so great that it is necessary to shorten the rope by cutting out a piece of it.

465. Remarks Concerning Rope Drives.—With the English (also called *multiple*) system, the breaking of a rope need not interfere with the operation of the drive; a new splice can be made, or a new rope can be put in at the week end. With the American system, where only one rope is used, a break is more serious; and it is therefore necessary to have more frequent inspection. Generally, some kind of a tell-tale is used; this is really a tell- 'tail,' as it indicates a broken strand or a raveled splice. Some claim that in the American system the loss in power is less and the stretch is evenly divided, while in the English system some ropes take more load than others, and a greater expense in ropes derives from that source. Also, with the English system, there are as many splices as there are grooves, while with the American system, only one splice is required for each drive.

Ropes must not be allowed to drag over any shafts that may pass beneath them; this may score the shaft, as well as wear the ropes. Manila ropes, particularly, must be taken up because of the stretch. Sometimes the original splice lasts until the rope is worn out, as ropes do not all stretch alike; in any case, a second splice is usually all that is needed. A good workman will make a new splice in one hour.

Some engineers recommend a slack-rope pit, the bottom of which is below the line of centers of the pulleys a distance equal to $0.24L$, in which L is the distance between the centers of the pulleys (sheaves).

It is interesting to note that the rope drive is, in a sense, a return to the original drive, with belts running from section to section. Changes of draw were made then by pasting on (or taking off) a layer of canvas or leather on the various pulleys; cone pulleys were not yet in use. Some of these old timers are still running.

The splicing of a rope is a millwright's job, and it may be a work of art. It requires knack and skill; and the man who can make a good splice has a right to be proud of the job.

466. Placing Spliced Driving Ropes on Pulleys.—If possible, ropes should be placed in a warm room on arrival, there to remain a week at least, or until required; this helps to season the twist, and it makes them more flexible.

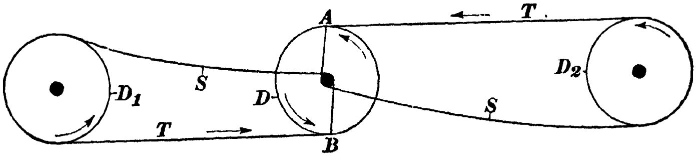


FIG. 139.

Before passing previously spliced ropes (English system) over their respective shafts, they should be stretched out in blocks, to the length marked on each coil. All clutches having been thrown out, the relative positions of the various drives will suggest the order in which the ropes are placed on their sheaves; for example, referring to Fig. 139, A would be passed on from the near side of the driving sheave and B from the far side. See that the ropes are already on the driven sheaves D_1, D_2 in either case; but before this is done, it is advisable to place a thinner rope, of any material, say about $\frac{7}{8}$ inch in diameter, in the bottom of the groove, the length being equal to the circumference of the groove; this acts as a *slipper*, and prevents undue strain when the rope is forced on the driver. The 'slipper' can be readily removed as the sheave revolves.

The splicings on either side of the ropes are distinguished from the remainder of the rope by the ruffled ends; they should be

placed near the driver D, on the slack side S. They are thus kept from buckling around the shaft, or from coming into contact with the sheaves until the ropes are well in position. The tight side T of the ropes is then passed onto the driving sheave as far as shrinkage will allow, which may be considered as about the position of A and B, and is then lashed in position, the lashing being drawn over the pulley rim and tied to an arm on the other side. The rope will appear rather tight on going on, but it will soon gain an easy driving tension after running awhile. If not provided with a barring tackle, the driving sheave may be drawn around by means of blocks.

THE FERGUSON AND OTHER DRIVES

467. Description.—An element of what is called the **Ferguson drive** is shown in Fig. 140. Corresponding letters have the same significance as in (*a*), Fig. 134. This drive uses twist belts, with idler (guide) pulleys, to transmit the power from a main variable-speed shaft (parallel to the machine) to the intake shafts, which are at right angles to the variable-speed shaft. In the Marshall drive, this change in direction was accomplished by the use of bevel gears.

Referring to Fig. 140, in which (*a*) is a plan view, (*b*) a front elevation, and (*c*) a side elevation, the main driving shaft S is located in the basement; it carries the driving cone pulleys P, which are belted to the follower cones P', each of which is on its own jack shaft S' above the machine-room floor. Each jack shaft carries a clutch C and a driving pulley K. Pulleys L are on the intake shafts, the axes of which are at right angles to the axes of the jack shafts, and the problem is to transmit the power from K to L by using a belt; and this is effected by using two guide pulleys H and J.

468. Locating the Guide Pulleys.—To locate the guide pulleys, it is necessary to make use of the following principles: In tracing the course of the belt, call the pulley toward which the belt is traveling, the **receiving pulley,** and the pulley from which the belt is coming, the **leaving pulley;** every pulley in the set will be both a receiving and a leaving pulley, according to whether the belt is coming on it or leaving it. If a plane be passed through the middle of the face of a pulley and perpendicular to the axis

of the pulley, it is called the **middle plane** of the pulley. Bearing these definitions in mind, the belt is guided in accordance with the two following principles: First, the belt may *leave* a pulley at any angle (say up to 90°); second, the center line of the belt must lie in the middle plane of the *receiving* pulley. Now applying

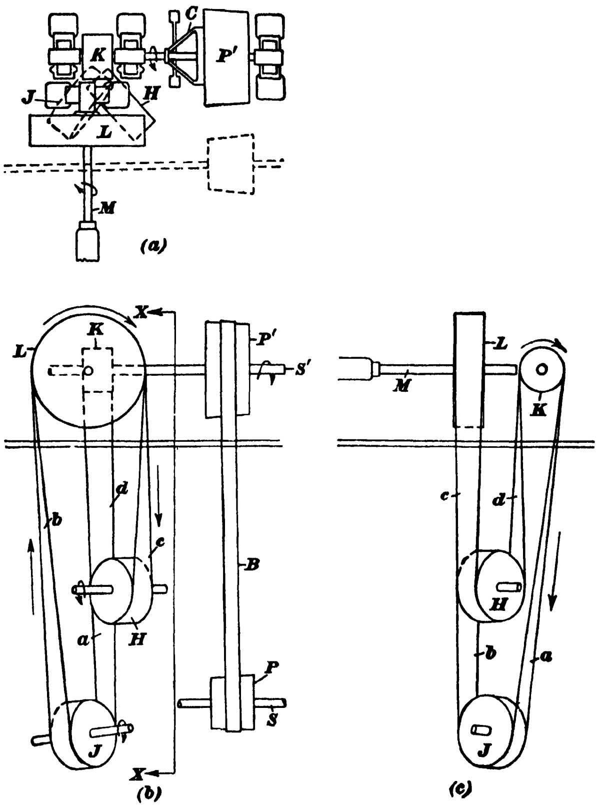


FIG. 140.

these principles to Fig. 140, it is evident from the drawing—see also view (*c*)—that the axis of the jack shaft S' carrying P' and K is *behind* the middle plane of pulley L. Tracing the course of the belt, the belt leaves K, passes down and around (behind) J, up and around L, down and around H, and up and around K. For convenience, the different parts of the belt have been lettered *a*, *b*, *c*, and *d*, in the order of travel from the point of leaving the pulley K.

According to the second of the above principles, the center line of a must lie in the middle plane of J, and the center line of b must lie in the middle plane of L; but since K is behind L, it is necessary to turn J so its axis makes an angle with the middle plane of L; and since the belt can leave K at any angle, a position can be found for J that will fulfill the conditions regarding the center lines of a and b. The center line of c must lie in the middle plane of H, and the center line of d must lie in the middle plane of K. By turning H so its axis makes the proper angle with the middle plane of K, a position can be found for H that will fulfill the conditions regarding the center lines of c and d. The arrangement of the guide pulleys for the other cases is effected in a similar manner. Since the belt is necessarily twisted by the changes in direction, this drive is what is called a **twist-belt drive.** The direction of travel of the belt cannot be reversed without changing the positions of the guide pulleys; because it would then violate the second principle, and the belt would run off the pulleys.

A crossed belt is used instead of the open belt B when it is necessary for pulley P' to turn in a direction opposite to that of shaft S and the corresponding pulleys on the other jack shafts, as in the case of the last press rolls.

469. Other Types of Drive.—Another type of drive, of which there are several installations, is known as the **Crandall drive.** This is a variation of the Marshall method of transmitting power at right angles from the line shaft to the section intake shafts, all of which run in ball bearings. This is accomplished by means of large paper cones on the line shaft and iron cones on the intake shafts. Both parts of each pair are adjustable, so as to get close and accurate changes of speed for each section, as required.

In England, a detail of rope drive has been developed that takes the place of a clutch, and has met with considerable favor; one form is called the **Lloyd-Hutchinson transmission,** while a second form is called the **White transmission.** The first form is usually identified with the Walmsley paper machines, and the second form with the Bertram machines. The cone pulleys for each section of the machine are set one vertically above the other. The driving pulley is mounted at one end of a lever or 'cradle' and rests in the loop of the belt, which hangs from the other cone

pulley. When any section is not running, the lower pulley is raised out of contact with the belt, and then turns idly. To start the section, the cradle is tipped, and the pulley drops into the loop of the belt, gradually picking up the load until the section is up to speed. In the Lloyd-Hutchinson drive, the cradle has a quadrant gear to balance the pulley; a worm, operated by a hand wheel on the machine-room floor, engages the gear and lifts or lowers the pulley into position. In the White drive, a form of toggle joint (a compound lever), operated by a lever arm, is used to lift or lower the belt pulley. It appears that the Lloyd-Hutchinson device affords more opportunity to vary the tension on the belt than that used in the White drive.

On some recent American machines, the dryers are driven by a chain that runs on sprockets attached to the dryer heads. The drive is enclosed, and the chain dips into an oil bath. (See Fig. 82.)

BELT ACTION UNDER WORKING CONDITIONS

470. Belt Tensions.—A diagrammatic representation of two pulleys connected by a belt is shown in Fig. 141. For con-

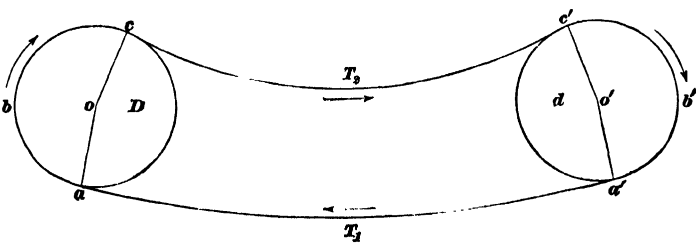


FIG. 141.

venience, the two pulleys D and d are of the same diameter, D being the driving and d the driven pulley, both turning in the direction indicated by the arrows. The part $a'a$ of the belt is called the **tight side,** and the part cc' is called the **slack side.** The belt goes on pulley D at a and leaves it at c, and the arc abc is called the **arc of contact;** for the driven pulley d, the arc $c'b'a'$ is called the arc of contact for that pulley. When the two pulleys have the same diameter, the length of the arc of contact on both pulleys is the same. As pulley D turns, the friction between it

and the belt creates a pull or **tension,** as it is called, in the tight side of the belt, and this tension is indicated by T_1. There is also a tension in the slack side, indicated by T_2, but it is less than T_1. The difference between these two tensions is the driving force transmitted to the driven pulley *d*, and the greater this difference the greater the amount of power that can be transmitted by this arrangement. In actual practice, a normal value for the ratio of the two tensions is 3.57; that is, $T_1 : T_2 = 3.57 : 1$, or $T_1 = 3.57 T_2$.

The value of the tension T_1 may be considerable; but whatever value it has it produces a *strain* (stretch) in the belt, and the greater the tension the greater the strain. Assuming, for example, that $T_1 = 3.57 T_2$ the stretch (elongation) in the slack side will be only $\frac{1}{3.57}$ of that in the tight side, since the amount of stretch is directly proportional to the pull. This difference of stretch must all be accounted for between the points *a* and *c*, along the arc of contact, on the driving pulley, *i.e.*, the belt must shorten that amount in going from *a* to *c*. A somewhat similar condition exists on the driven pulley *d*, except that the belt must lengthen that same amount in going from *c′* to *a′*. The combined result is that the belt slips on either pulley, and this effect is called the **creep** of the belt.

471. Slip of Belt.—In addition to the creep of a belt, there is also a certain amount of **slip,** *i.e.*, the belt slides on the pulley. It is stated by Unwin in his "Elements of Machine Design" (edition of 1919) that: "The earlier writers assumed there was no slipping of the belt on the pulley, and that if slipping occurred the belt would cease to drive. So far is this from being the case that there is always some slipping of the belt." Further, as the result of a very large number of experimental tests conducted by Prof. W. M. Sawdon, of Cornell University, it was found that with a dead load, the slip varied, during a period of 30 minutes, between 0.5% and 15%, and, during another similar period, it varied between 1% and over 10%. Moreover, he found that the slip is continually varying. The slip values here stated include the creep also, as is usually the case.

Now if there were no slip (or creep) and both pulleys were of the same diameter, the peripheral speed of one pulley would be exactly the same as that of the other, which would be the lineal

speed of the belt. But when there is slip, as is always the case in practice, the driven pulley will turn slower than the driving pulley. Furthermore, if the pulleys are of different diameters, the amount of slip will be greater, since the arc of contact on the smaller pulley will be smaller than that on the larger pulley.

The slip is also affected by variations in the load. To consider one case only, it was found, in connection with the tests above mentioned, that with an increase in the load of 20% (at which point, the belt was supposed to be normally loaded, *i.e.*, $T_1 \div T_2 = 3.57$), the slip changed from 2.26% to 3.29%; this means an increase in the speed variation of the two pulleys of more than 1%. For, taking the speed of the driving pulley as 100%, the speed of the driven pulley before the load was increased was $100 - 2.26 = 97.74\%$; after the load was increased, the speed was $100 - 3.29 = 96.71\%$; then, $\frac{97.74 - 96.71}{97.74} = 0.0105+$, or 1.05%.

472. Application to Paper Machine.—All the paper-machine drives so far discussed use belts and pulleys for their operation; consequently, their use has a very decided effect on the draw (see Part 2). Suppose the sectional draw is set at less than 1%, perhaps as low as 0.5%; suppose further that a 20% increase in the load takes place, such as may be caused by the addition of weights or increase of bearing friction. Then, as mentioned in the last paragraph, there will be an increase of 1% in the slip. If the draw is set for 1%, it will then be increased to $1 + 1 = 2\%$, an increase of $\frac{2 - 1}{1} = 1$, or 100%. If the draw is set for 0.5%, it will be increased to $0.5 + 1 = 1.5\%$, an increase of $\frac{1.5 - 0.5}{0.5} = 2$, or 200%. This change in the draw is caused by the change in the load only; and it has been previously shown that with belt transmission, the slip is continually changing, even under a uniform load. Therefore, a uniform draw cannot be obtained when the drive is operated by belts and pulleys.

473. Action of Belts on Cone Pulleys.—One of the most important factors in connection with the power transmitted by a belt is the amount of belt surface in contact with the pulley, and this, in turn, depends on the arc of contact and the width of the belt. With flat pulleys, the width of the belt may be increased

almost indefinitely; but such is not the case with cone pulleys, as will now be shown.

The cone pulley C, Fig. 142, is supposed to be the driven pulley. The smaller diameter is indicated by the line NN and the larger diameter by MM. AB represents the belt, and the points of extreme contact of belt and pulley are indicated by P and Q. Pulley C is making a certain number of revolutions per minute (r.p.m.), and all points on it, as N, P, Q, and M, are making the same number of r.p.m. But the peripheral speed of M is greater than that of N, because the diameter at M is greater than at N; consequently, the peripheral speed of Q is greater than that of P. Normally, the intensity of contact between the belt and pulley is greater at BQ than at AP. Now suppose that the center of the driving force of the belt is located at the points BQ, then the slip at AP must be considerable, the amount depending on the width of the belt. Or, suppose the center of the driving force is toward A, say about one-third the distance BA, then the point Q will be running faster than the belt and the point P slower than the belt; in other words, the point Q, which is most closely in contact with the belt, is actually acting to drive the belt, notwithstanding that this is the driven pulley that is being considered. After running for some time with the belt in the same position, an examination of the pulley will show that the surface at Q is bright, that a little farther toward A there is a dull surface, then again bright, and again dull—the result of a battle of frictions, positive and negative, so to speak.

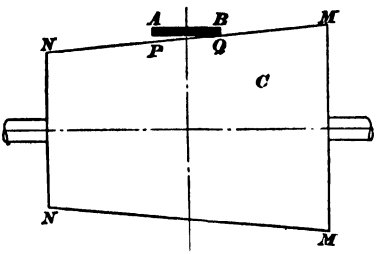


FIG. 142.

474. Loose-Belt Drive.—Through the use of a *tapered* loose belt C, with an outside straight face G, Fig. 143, around the drive-unit cone pulley A, and with a straight-face pulley on the variable-speed line-shaft pulley F, belts of any desired width can be used, so that enough power can be transmitted for the widest and fastest machine sections without undue wear and strain on the belt. In addition to this feature, a suitable idler (jockey)

pulley *E* is provided on paper-machine drives for each section belt, by means of which the driving belt is tightened up, thus giving smooth and gradual acceleration in starting up the sections and until up to speed. When the idler pulley is swung back, the belt is released; it hangs loosely around the line-shaft pulley *F*,

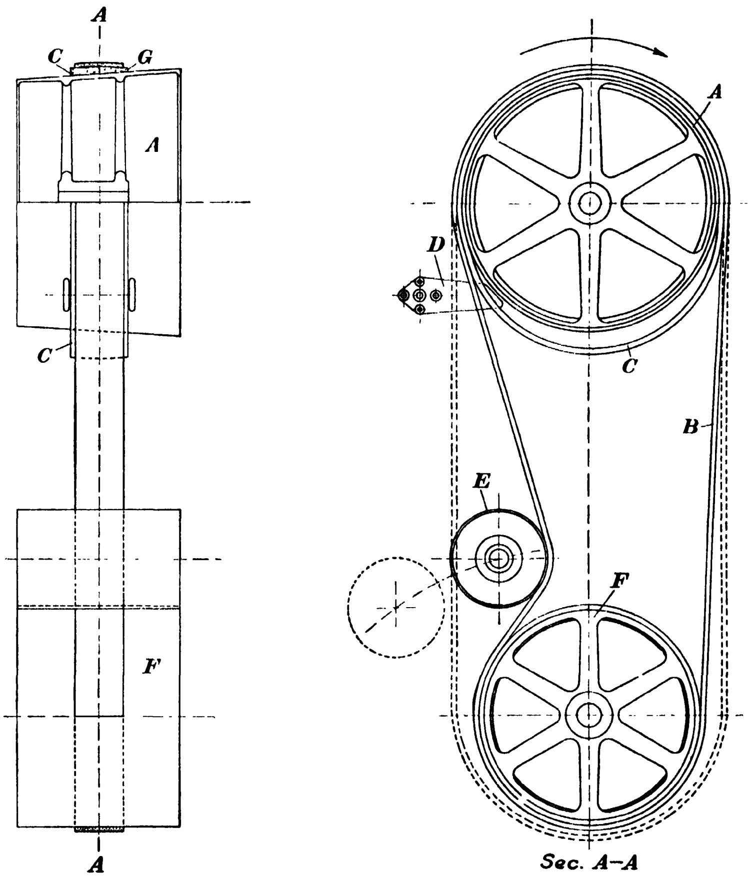


FIG. 143.

thereby stopping the section. The very large pulley and belt surface available for radiating and convecting heat to the atmosphere in starting up a high-inertia section is far greater than is the case with the ordinary friction clutch, and there will be less temperature rise.

A suitable means for the engaging and disengaging of the idler pulley from the belt through the operator's pilot lever gives a sensitive 'feel' to the operation, and provides reliable 'inching' as well as normal starting and stopping.

Referring to Fig. 143, the cone pulley *A* has twice the normal taper it would have if the driving pulley *F* were also a cone pulley instead of being straight. The belt shifter *D* may be operated manually or hydraulically, causing the idler (jockey) pulley *E*, which acts as a belt tightener, to maintain uniform belt tension. The inside face of the loose belt *C* has the same taper as the cone pulley; hence, there is no tendency for the driving belt to 'climb' the pulley, wear of the loose belt on the shifter fork is reduced, and speed control is more accurate. The full lines show the driving belt in running position, and the dotted lines show it in idle position.

ELECTRIC DRIVES

GENERAL CONSIDERATIONS

475. Two General Methods.—The application of electricity for the driving of papermaking machines is one of the most important developments that the paper industry has experienced since the invention of the Fourdrinier machine; it ranks with the application of steam to the drying of paper, which took the place of the wood or charcoal fires that served at one time to furnish the heat required for the evaporation of the water from the sheet.

The use of electricity as a driving force is generally effected in two distinct ways: first, a big motor of the variable-speed type, or else one of constant speed with a speed changer, is used to drive the ordinary type of line shafting or rope drive for the variable-speed end of the machine; second, a number of motors, each driving an individual part, are so connected by a control mechanism that all run in harmony. The first method permits variation in the speed of the whole machine within the range of the main motor; but variations of speed for the individual sections, because of localized conditions, are still dependent upon belts driven from cone pulleys, as previously described. The second method not only makes possible a uniform, immediate, and simultaneous change of speed throughout the entire machine but it

also makes possible a very nicely graduated speed change on any section where conditions may be even momentarily altered; and this is accomplished instantaneously and automatically without requiring the use of belts to transmit any material amount of power.

476. Comparison of Mechanical and Electric Drives.—The disadvantages accompanying belt transmission and the use of long lines of shafting, with spur gears, clutches, belts, bearings, etc., which result in a loss of power and accurate control or delicate adjustment, have been the main factors in bringing about the development of the sectionalized electric drive, which generally conserves and reduces the power requirements and permits of instantaneous and automatic adjustment for the slightest changes in the speed of any section of the machine. In fact, with electric-drive equipment, the changes of speed that will cause the corresponding adjustment of the motor speed of any section have been found to be often but a fraction of the variation of speed that frequently occurs merely from the slippage of belts on the ordinary types of mechanical drives. The speed variation may range from 2 to 1 for news machines to 8 or even 15 to 1 for specialties.

With the sectional individual-motor drive, the maintenance expense is small; and substantially less power is required, as compared with the Marshall-train drive, owing to the elimination of the cones, gearing, and shafting. In the case of the motor drive, the necessity for basement space for the drive is eliminated, and there is considerably less floor space required on the machine-room floor.

477. Mechanical Explanation of the Sectional Drive.—In order to visualize the operation of the sectional drive, and to understand its evolution, a comparison of one of the earlier makes of sectional drive with the well-known Marshall train may be helpful. In a general way, this illustrates the principles of each type, to be described in detail later.

Diagram (1), Fig. 144, represents four sections of a machine operated by a Marshall train that is driven by the motor *M*; for simplicity, the clutches have been omitted. It is easy to see that if it were not for the necessity of adjusting the draw between the sections, the machine might be driven as in diagram (2), in which the main intake shaft has been omitted, and the motor or

engine has been direct connected to the gear shaft. With this arrangement, all the sections must run at a relatively uniform speed, regardless of load changes on any section.

Diagram (3) shows a further modification of this scheme, in that the main driving motor or engine M has been replaced by individual motors, M_1, M_2, etc., which are direct connected to the intake shafts, as shown, but leaving the miter gears as before. With this arrangement, the intake shafts must evidently maintain

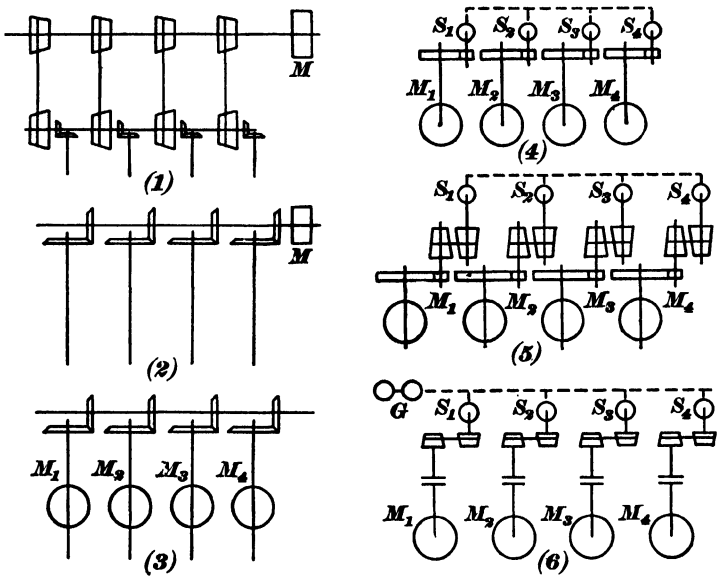


FIG. 144.

their relative speeds regardless of changes in the loads, some gears 'holding back' and others 'helping out' the main motors.

It is an established fact that synchronous motors and generators that have the same number of poles and that are furnished with current of the same frequency must run at the *same speed under all conditions*, up to their breakdown capacity, which corresponds to the strength of the gears in diagram 3. Therefore, synchronous machines, S_1, S_2, etc., may be substituted, as in diagram 4, for the miter-gear shaft shown in diagram 3, each main motor driving an independent section of the paper machine. Any changes in load or any tendency to change the speed of the main

motors M_1, M_2, etc., would then be compensated for by the synchronous machines, the effect being the same as that obtained by using the miter gears as shown in diagram 3.

Thus far, no provision has been made for adjusting the draw between the several sections; but in diagram 5, the shafts connecting the synchronous machines S_1, S_2, etc., have been opened up and pairs of cone pulleys inserted as shown, so as to vary the speeds of the main motors M_1, M_2, etc. The synchronous machines must always run at the same speed under these conditions; therefore the ratio of the speed of any synchronous machine to that of the main motor to which it is connected can be readily altered by shifting the belt on the cones.

A further development of the drive shown in diagram 5 has synchronous machines S_1, S_2, etc., which control the resistance in the field circuit of the driving motors and, hence, also, the power supplied to them, so as to keep the main motors in step. They are not mechanically connected to the main motors M_1, M_2, etc., but are driven independently, at constant speed, by a master motor-generator set G, as indicated in diagram 6.

Much has been said and published about belt slippage in connection with paper-machine drives; and were it not for the fact that only a small amount of power is ever transmitted by the synchronous-machine belts, instability might be expected. The fact is, however, that only a part of the increases and decreases in the normal load on any particular section is handled by the synchronous-machine belts; and the fact that the capacity of these belts is far in excess of the amount of power they ever transmit, eliminates this objection, a fact that is borne out by the successful operation of the machines now in regular use.

478. Sectional Individual Drives.—Even the most dependable of the mechanical systems of paper-machine variable-speed drives[1] has many disadvantages, because of losses in shaft bearings, irregularities caused by belt slippage, etc. In sectional paper-machine drives, direct-current motors are used,[2] because of their adaptability and operating characteristics. These motors, when

[1] By this is meant the means of transmitting power from the prime mover to the various parts of the machine.

[2] In Europe, and especially in England, extensive use has been made of the adjustable-speed alternating-current commutator motor for sectional paper-machine drives, since this type of motor does not require any conversion apparatus (see Arts. **522–528**).

properly designed and controlled, can be operated at any desired speed within predetermined limits, and very fine gradations of speed differences between sections can be obtained. Each motor is connected to its particular intake shaft[1] by positive mechanical means, thus doing away with belt slippage. The speed of the entire machine can be adjusted within the desired range without paying any attention to the individual motors. The motors are held in proper speed relationship by simple devices, which vary in the different successful designs of electric drives now obtainable, but which, in each case, operate on the motor field.

Shunt-wound direct-current motors are applied to each section of the paper machine. These motors may be direct connected to the section intake shafts, or they may be geared to these shafts by suitable gearing—either helical, herringbone, or worm gears, or chain drives.

In most paper mills, the power supply is alternating current; therefore, some form of conversion apparatus is necessary to supply the paper-machine motors with direct current, usually one of the following:

a. The synchronous motor-generator set with direct-connected exciter, which is probably the most common form.

b. The turbo-generator set with direct-connected exciter, where the turbine of the non-condensing type furnishes low-pressure exhaust steam for the dryers.

c. The power steam-balance set, which consists of a non-condensing turbine, a direct-current generator, an exciter, and an alternating-current synchronous machine that is connected to the mill system and really acts as a speed governor for the turbine. The alternating-current machine may act as a motor or as a generator, depending on load conditions of the direct-current generator, and permits a perfect steam balance at all times, since the turbine value is set for the exact steam requirements. In case of power failure on the alternating-current system, the turbine reverts to its own speed governor. The auxiliary starting generator can, of course, be incorporated in any of these sets.

Paper-machine drives are usually of the Ward-Leonard or adjustable-voltage type, and speed range is obtained by varying

[1] The *intake shaft* transmits power from the drive mechanism to the sections of the machine.

the generator voltage, except in those cases where extremely wide speed ranges are desired, and a combination of both motor and generator field control is employed to obtain greater stability.

The means for adjusting the generator voltage and, incidentally, the speed of the paper-machine motors as a group, may be hand operated or of the automatic type; and though generally located in the machine room on the front side of the machine, the control may be placed in any other convenient location. The paper-machine speed is held constant, at any speed setting, by a speed regulator, which controls the master section of the machine and, through it, all the other section motors. Draw adjustment of the individual motor units is made by hand, and the speed is held constant by means of sensitive and accurate speed regulators on each motor.

The principal difference between the several varieties of paper-machine motor-driven systems lies in the methods adopted to control the slight difference in speed that must be maintained between the different sections, *i.e.*, in controlling the draw.

479. Advantages of the Sectional Electric Drive.—Although the first cost of the earlier sectional electric drives was undoubtedly greater than the existing forms of mechanical drives, the older drives were not suitable for high-speed machines. The gradual improvement in mechanical drives to meet high-speed conditions and greater power requirements has eliminated any price differential that formerly existed, and the many advantages to be obtained with the modern sectional electric drive warrant most serious consideration in connection with every installation, whether on large or small machines.

With the increasing trend toward the use of rubber-covered suction-press rolls, suction drum rolls, dual presses, extractor rolls, top-roll drives, rubber-covered pressure rolls for Yankee dryers and special coating sections, the modern paper machine is becoming more expensive; incidentally, so is the drive, whether mechanical or electrical. There is no form of mechanical drive that will tell an operator what is happening; and since this large investment must be protected, the electric drive is the only means that will give him a clear indication of what is happening at all times, and perhaps avoid costly maintenance.

Among the many advantages of the sectional electric drive are:

a. Each section is an entirely separate unit: this permits immediate detection of any trouble in the paper machine itself, since each section is driven by a motor that is provided with an ammeter, which will provide immediate indication of any trouble, such as hot bearings, seizing, etc., that may occur. Trouble of this nature can therefore be investigated and probably remedied before it has become serious.

b. In every case where a sectional electric drive has been used, it is claimed that the power consumption has been approximately one-half to two-thirds of that of a similar machine equipped with a mechanical drive; and this claim applies to both high-speed and low-speed machines.

c. The elimination of all belts and ropes also eliminates annual belt and rope costs; this is a considerable factor in the operating costs of a paper mill, especially on high-speed machines.

d. All paper-machine operators realize the difficulties in starting up heavy, large machines with belts, and the difficulty of inching the various sections; with sectional electric drives, these difficulties are overcome, and the handling of the paper machine is greatly simplified. It is possible to reverse the calender section in the event of 'plugs' without the necessity of lifting the calender rolls, and such reversing is very simple and takes but a very short time.

e. The back side of the machine is rendered almost as accessible as the front side, because of the absence of large belts, ropes, and gears; in addition to tending toward cleanliness and enabling closer attention to the oiling of the paper-machine back-side bearings, this reduces greatly the personal hazard to the paper-machine operator.

f. Owing to the very even starting torque exerted by electric motors, particularly motors of the direct-current type, no sudden jerks are transmitted to the paper machine in the starting up of the various sections, with the result that there is less strain on the various parts of the paper machine, such as dryer gear wheels.

g. No basement for drive purposes is required under the machine; and where a basement already exists, it can be utilized for storage purposes, etc.

h. A material saving of floor space is effected.

There are three principal types of electric drives; *viz.*, the General Electric, the Harland Patent Interlock, the Westinghouse. A brief description will now be given of each of these drives.

NOTE.—It is not within the scope of this textbook to impart full information regarding details of construction and adjustment of this apparatus; but the principles involved and the practical operation of the various types of electric drives are discussed and explained. It is recommended that the student review the treatment of generators and motors that is given in Elements of Electricity, Vol. II, before proceeding further with the subject of electric drives.

GENERAL ELECTRIC SECTIONAL PAPER-MACHINE DRIVE

480. Speed of Paper-Machine Units.—Strictly speaking, the paper machine is a group of individual machines, or units, each with its own peculiar function, operating concurrently and so closely related as to make a continuous sheet of paper. The speed of these various units is not the same, and may vary for different grades of paper; but the *relative speeds* of these units must be maintained within extremely narrow limits.

481. The Sectional Electric Drive.—As its name implies, the **sectional electric drive** utilizes an individual motor on each section of the paper machine, thus eliminating the back-line shaft, cone pulleys, belts, back stands, and clutches. In the United States and Canada, the motors have largely been of the direct-current shunt-wound type, connected to the in-driving shafts of the paper machine through herringbone gear reducers. All these drives have been of the adjustable-voltage type; and while most of them have utilized rheostatic starting for the individual motors, many of them have been furnished with auxiliary starting generators.

The earlier G.E. (General Electric) sectional drives were of the synchronous tie-in type, utilizing slow-speed direct-connected motors, with synchronous motors connected to them through a pair of cone pulleys and a belt. The synchronous motors were connected to a common bus, entirely separate from any other power system, and held the direct-current driving motors in synchronous relation, regardless of the speed at which they were operating. This type of drive was rather expensive, but it was developed at a time when the need was great and the existing

mechanical drives could not meet the operating conditions. Since many of these earlier drives are still in use, a brief description is given herewith.

During the past nineteen years, the G.E. sectional drive has passed through several stages of development and improvement. While many of each type are in successful operation, it is, perhaps, advisable merely to indicate herein the progress, as

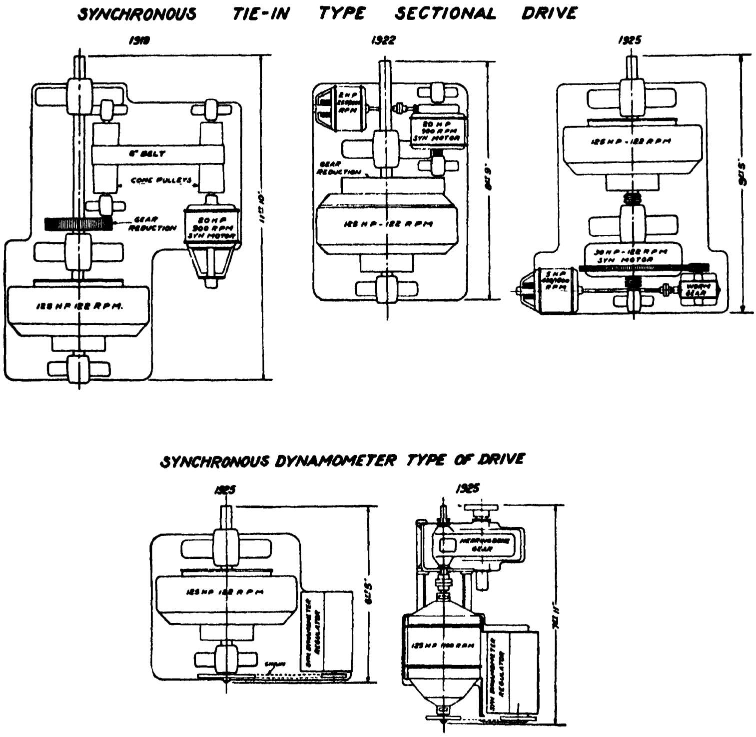


FIG. 145.

shown diagrammatically in Fig. 145, and then to give a description of the most modern G.E. sectional drive and explain its operation.

482. Synchronous-Motor Regulated Drive.—The first General Electric sectionalized drive consisted of one unit for each section of the paper machine. Each unit consists of a direct-current motor *A*, Fig. 146, and a synchronous motor *B*, which has about

20 per cent of the capacity of the direct-current motor. The synchronous motor is driven from the direct-current motor through a gear reduction *C* and a set of cones and belt *D*, which permit of a total range of speed of 12%. The motors and cones are mounted on a common base, and the main section motors are direct-connected to the section of the paper machine by shaft *E*. All the motor units are driven from a single generator, on which the voltage is varied by means of field control to obtain a variation in speed on the whole machine. For ranges

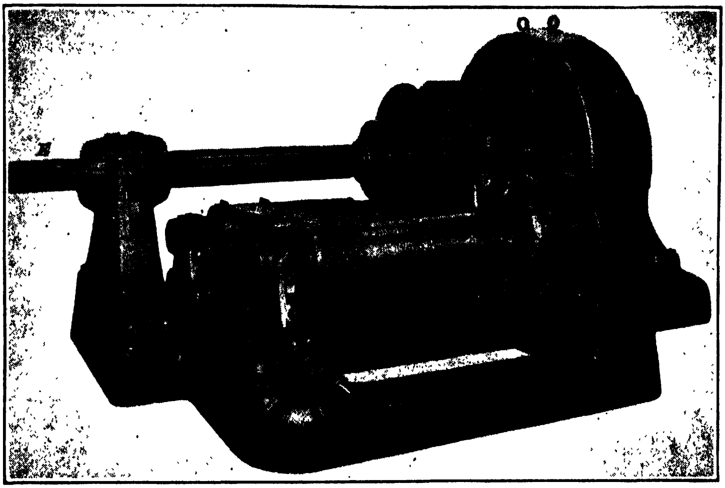


FIG. 146.

in speed not exceeding 6 to 1, field control on the motors is not necessary; but beyond this range, a combination of voltage and field control is required to insure good speed regulation.

483. Characteristics of Synchronous Motors.—A synchronous motor may be operated either as a generator or as a motor. If alternating current be supplied to its alternating-current terminals, it will run as a motor, at the same speed as the generator that supplies the current, the current being of proper voltage and frequency. If it is being driven by a belt at proper speed, it will generate alternating current of a frequency that is directly related to the number of poles in its field and the revolutions per minute of its shaft. To operate either as a motor or as a generator, the field of the machine is energized by a direct-current supply,

which is brought from a source external to the machine. The essential characteristic of this machine is that, when operated as a motor, its shaft revolves in almost perfect unison with the shaft of the synchronous generator that supplies the alternating current.

484. Application of Synchronous Motor to Paper Machines.—This principle of the synchronous motor (*i.e.*, of acting either as a generator or motor) is utilized to secure harmonious operation of the section motors. All the synchronous motors on the various section motors are electrically connected together by a common bus[1]; the 'A' terminal of each motor is connected to the 'A' bus, the 'B' terminal to the 'B' bus, and the 'C' terminal to the 'C' bus.

So long as all the synchronous motors on the machine revolve at the same speed, or are in step, no current flows in the bus. However, when one of the section motors tends to run at a lower relative speed than the others, there is a phase displacement, and the synchronous motors attached to all the other section motors operate as generators; this has the effect of reducing their speed until it reaches the same value as the speed of the offending motor; then all the motors operate at the same speed and there is no change in the draw.

To make local variations in speed on an individual section motor, the belt that connects the synchronous motor with its corresponding direct-current motor runs over slightly tapered pulleys. A belt-shifting arrangement is used to change the position of the belt, and thus to change very slightly the relative speeds of the main drive motor and the synchronous motor.

485. Direct-Current Units.—All direct-current units are operated in multiple from the common generator bus (conductor lines). All direct-current motor fields and synchronous motor fields (also the generator field) are connected to the exciter bus, which is of sufficient capacity to excite all machines. (The exciter supplies the field current for all these other machines.)

Each direct-current motor has a drum controller (like that on a trolley car) and rheostat in its circuit, for individual starting. The synchronous motor is connected to the dead bus by means

[1] Sometimes called the **dead bus**, because it is not furnished with outside current for driving. By **bus** or **busbar** is meant the main conductor, which carries a heavy current for a number of machines.

of a push button, but this connection can be made only when the controller is on the last point. This connection is made only when all sections are running at the correct speed, if any motors are started independently.

486. Starting and Operating.—When starting the paper machine as a unit, the drum controllers in the direct-current motor circuits should all be on the last point, with the synchronous motors connected to the dead bus. Since the synchronous motors are geared and belted to the direct-current motors, they will also turn over with them; and since they are all connected to the same bus, they will start up in synchronism (at the same number of revolutions per minute). To bring the machine up to speed, the generator field is strengthened by turning the hand wheel on the auxiliary control panel; this will cut out resistance and allow a stronger current to flow.

487. Importance of Uniform Relative Speeds.—To make paper successfully, the relative speeds of the various sections must not change; that is, the motors must be synchronized, and they must be free from any individual change in speed. The speed of one motor may differ from that of another; but when it has once been set for certain proper conditions, it must not vary relative to the others. This is the function of the synchronous motors; and within their capacity, they will hold the direct-current motors in step absolutely. The speeds of the different sections of the paper machine are not all the same—there is a slight increase from the wet end to the dry end—and this percentage difference may vary slightly for different grades of paper and under different operating conditions. This variation produces the *draw*, and it is taken care of by shifting the belt on the cones, a procedure that can change only the direct-current section motor speed, since the speed of the synchronous motor is fixed.

488. Automatic Adjustment for Changes in Load.—In actual operation, any change in the load on a particular section, caused by changing the weights or otherwise altering conditions, will be absorbed by the synchronous machine. If the load increase, the synchronous machine will act as a motor and aid the direct-current motor on that particular section, drawing its power from the remaining synchronous machines, which will immediately act as generators and distribute the load over the entire machine

drive through the dead bus. If the load decrease, the synchronous machine will act as a generator, supplying current to the remaining synchronous machines, which then act as motors and help the other direct-current motors. It will be seen that any change in the load on any section is immediately distributed over the entire motor equipment; this may change, though only slightly, the speed of the paper machine as a whole, but it cannot cause any change in the relative speeds of the various sections. For instance, suppose that there were 8 sections; then, instead of one section having its speed changed, say 1 foot per minute, the speed of the entire 8 sections would be changed only $\frac{1}{8}$ foot per minute.

So long as any synchronous machine operates within its capacity, either as a motor or as a generator, it will not be necessary to make any adjustments; but if the indicating wattmeter in the synchronous-machine circuit shows it to be using too much power, it may easily be brought back to zero by adjusting the rheostat in the direct-current motor field, so as to cause the main section motor to do its own work. This condition may indicate that some part of the paper machine needs attention.

489. Changing the Speed of a Section.—If it be desired to change the speed of one direct-current section motor relative to the others, it is changed relative to its synchronous motor (which is the same thing) by shifting the belt *D*, Fig. 146, while adjusting the strength of the field circuit by means of the field rheostat, which is operated by a hand wheel on the section-control panel.

490. The Modern G.E. Drive.—The modern G.E. sectional paper-machine drive is of the regulator type, wherein the regulator operates on the motor field to maintain substantially constant speed under varying load conditions. This method of speed control detracts somewhat from the motor torque at reduced speeds, and the wider the speed range the more marked this effect is. This characteristic is inherent in all direct-current motors, and, successfully to meet the operating requirements at reduced speeds, it is necessary to de-rate the motors. In other words, the torque delivered is of primary importance; and, if the motors are properly selected, the horsepower rating is of no practical value, except for comparison. It is good insurance to

have motors liberal enough to carry on under the most severe conditions of operation.

491. Control Panels.—The speed regulators, which are of the compensated *selsyn* (self-synchronous) type, and which give uniform speed of response at all operating speeds and provide an infinite number of control points, are mounted on the central control board, where they logically belong, away from the motors and machine room. Individual control of each sectional unit, giving starting, stopping, jogging, slow speed, and complete control of the whole machine as a unit, is handled from the auxiliary control panel in the machine room.

Hand-operated, waterproof master controllers for each motor, mounted on the front side of the machine, give the operator immediate response to his demands, and positive, definite draw adjustment for each section is obtained by means of selsyn units mounted on the front side of the machine. All equipment is readily accessible and space requirements are at a minimum; each motor, with its gear reducer and base, is a unit in itself.

492. System of Control and Power Supply.—Two systems of control have been used with sectional paper-machine drives: one, the rheostatic starting control for each individual motor; the other, the auxiliary starting generator.[1] Both systems have been used extensively, and each has its advantages.

The general source of power in paper mills is, invariably, alternating current; and since the paper-machine drive is an ideal direct-current application, conversion apparatus is necessary, as discussed in Art. **478.**

493. Motor Units.—The motors used for this service are all of the 40°C. rise, totally enclosed, forced-ventilation type, selected to meet the machine torque requirements throughout the operating speed range. Gear reduction units are of the herring-

[1] In the **rheostatic system of control,** each individual motor is started by means of a series resistance in the armature circuit and magnetic control, which permits of starting, stopping, inching, and slow motion on each section individually; whereas, with the **auxiliary starting generator system,** a separate starting generator is required, and each motor is started by gradually increasing the voltage on the starting generator.

The auxiliary starting generator system is no less expensive or simpler than the rheostatic system, since a system of interlocking must be used to prevent starting more than one unit at a time, and differential voltage relays must be used to transfer the motors from the starting generator to the main generator at the correct voltage. Flexibility is also sacrificed to some extent, though it does minimize peak loads on the main generator.

bone type, including base for mounting the motor, and high-speed couplings, designed to carry all the load the motors will deliver.

494. Control.—The control for the motors is of the contactor type, assembled as a unit control board, together with the generator panel and rheostat and synchronous panel. The selsyn speed regulators for the individual motors are also mounted on this board, away from the machine room. The water-tight drum-type master controllers for the sectional motors are mounted on the front side of the paper machine within easy reach of the operator, and give immediate response to his action. The 'draw' selsyn units are mounted directly over the master controllers, and give the operator definite, positive control of the draw adjustment.

The master selsyn unit for controlling the speed of the sectional units is generally driven from the first dryer section; the speed of this unit is held constant by means of a speed regulator, which operates on the main generator field.

495. Speed Regulators.—While careful attention must be paid to the proper selection of motors and control, the speed regulators are really the most important part of the drive. The ability of these regulators to respond quickly to load changes on the various section motors, and the accuracy with which they maintain speed, determines the success of the drive.

The G.E. speed regulator is of the selsyn type, compensated to give equal speed of response at all operating speeds of the paper machine. This compensation is automatically taken care of through a mechanical connection between the regulators and the main-generator field rheostat; it is extremely important, since the driving motors require a greater field adjustment at low speeds than at high speeds for the same load changes.

The use of a pressure-type regulator rheostat permits of an infinite number of operating points, and it assures the correct field setting to meet the load requirements exactly. The selsyn transmitter, with its cone pulleys and belt-shifting selsyn unit, shown in Fig. 147, is housed under a sheet-metal cover for protection; it is mounted next to the motor to be controlled, and is connected to it by means of a single V belt.

496. The Selsyn System.—A schematic diagram of a selsyn section assembly is shown in Fig. 148. The other sections have

similar units, except the section motor that drives the master selsyn generator. A transmitter unit is indicated in Fig. 148, and a speed regulator (differential receiver) unit is shown in Fig. 149.

Connected electrically between the master selsyn transmitter and each of the section selsyn transmitters, Fig. 148, is a differential receiver unit, Fig. 149, the shaft of which is connected

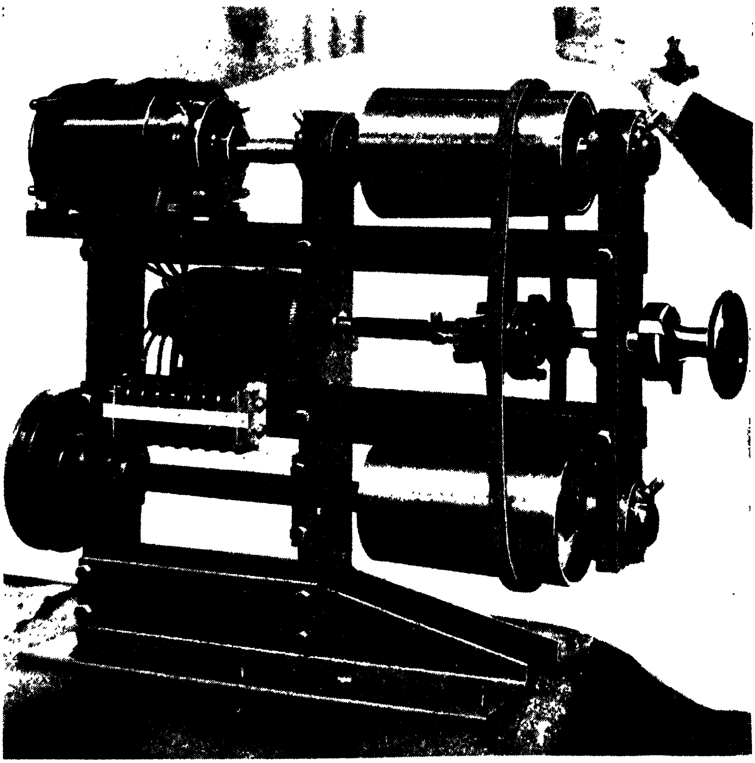


Fig. 147.

through a cam-and-lever system to a compression-type motor-field rheostat. If there is an angular displacement between the rotor of the transmitter driven by the section motor and the rotor of the master transmitter, *i.e.*, if the section motor tries to run faster or slower than the master, the differential selsyn receiver rotates to reduce this angle. This rotation is utilized, through a worm-gear drive and lever system, to increase or decrease the

pressure on the compression-type motor-field rheostat. The rotation of the differential units results, in both direction and amount, from the small current generated by the difference in speed of the section motor in comparison with the master.

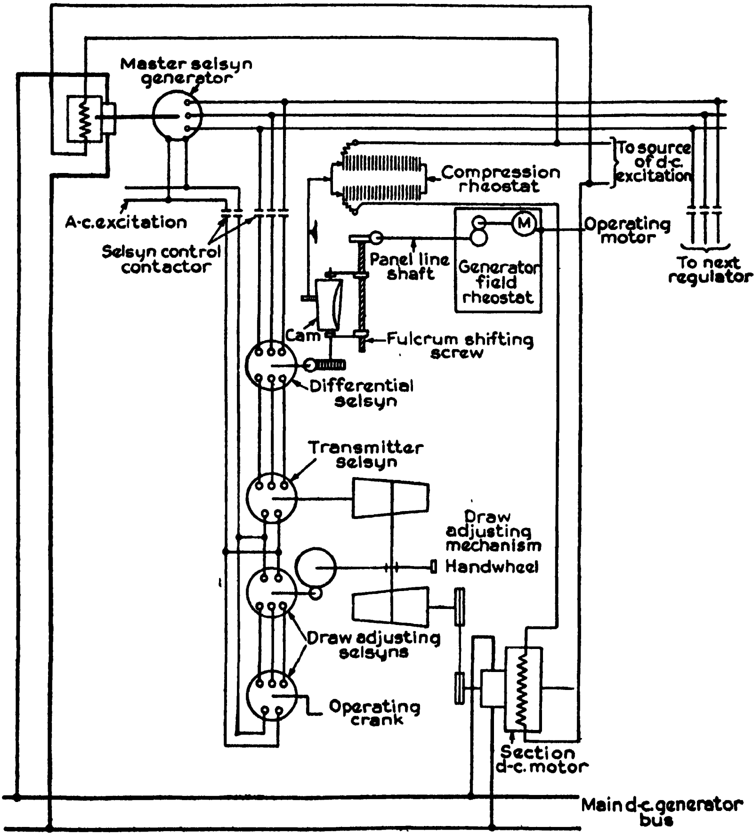


FIG. 148.

The resistance of a stack of carbon disks (see Art. **518**) varies inversely with the axial pressure applied to it. Thus the field current of the direct-current driving motor is changed by the rotation of the shaft of the differential selsyn unit, and the speed of the direct-current motor is held constant in this manner. This type of motor-field rheostat provides a speed-adjusting medium that has an infinite number of operating points. By shifting the

belt along the cone pulleys, Fig. 148, an adjustment may be made in the speed of the section motor. This may be done by the hand wheel or by the small, remote-controlled selsyn unit.

The differential selsyn receiver, shown in Fig. 149, turns the compensating spiral cam through a worm and gear. A lever

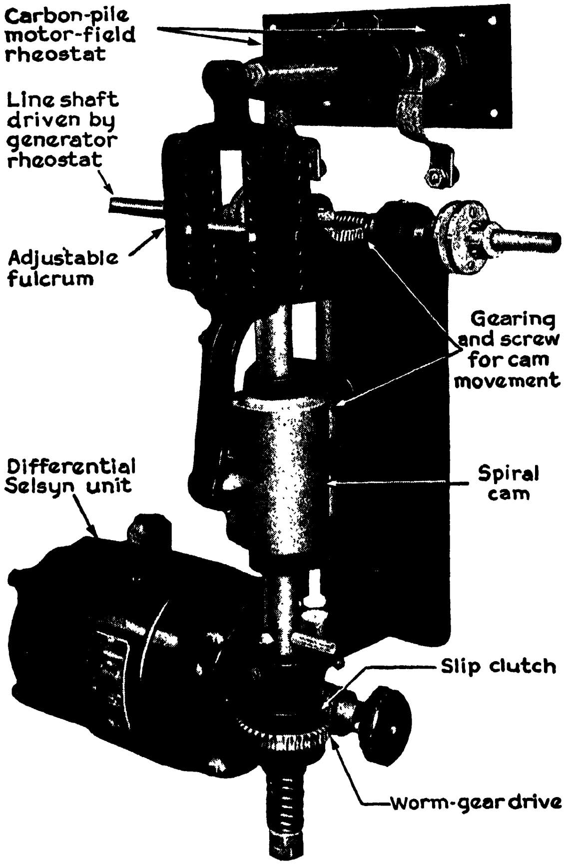


Fig. 149.

mechanism, operated by the cam follower, applies the pressure to the compression-type resistors.

In addition to rotation on its axis, the cam may be moved vertically, thereby presenting a different contour to the follower.

The rise of the cam follower, and the change in motor-field current for a given angular movement of the compensating cam, varies with the vertical position of the cam. Thus the field excitation change is adjusted by shifting the cam vertically. The vertical position of the compensating cam is automatically adjusted to provide the proper rate of response for every machine speed. The compensating cams are all moved simultaneously, by a shaft and suitable gearing, from the motor-operated rheostat that adjusts the paper-machine speed.

The low-inertia sections of the paper machine may respond more quickly than the high-inertia dryer sections. The gear and lever ratios of the speed regulator may be initially adjusted to provide the correct over-all rate of response for each section. Also, the speed regulator compensates for the difference in motor performance at normal and reduced operating speeds.

497. Progressive Draw.—In the more common system of draw adjustment, the speed of each sectional motor unit is adjusted individually to meet the operation requirements; and, if the speed of one unit is altered, it is usually necessary to correct the speed of all sectional units following it. However, the *progressive draw system*, as supplied by the General Electric Co., is highly desirable in some instances. With this system, the adjustment of draw on any motor unit automatically corrects the draw on all following units on the dry end of the machine, and, on all preceding units on the wet end, *i.e.*, on either side of the master section.

498. Tension Balance.—On many wide-range machines making heavy papers, it is possible to put sufficient tension in the sheet between the calender and the dryer as partially or fully to unload the dryer motor and, at times, even cause it to act as a generator. Of itself, this condition is not objectionable; but if a snap-off occur, the dryer motor will settle back, causing a loop in the paper immediately preceding the dryer section, which results in wrinkles and calender cuts. The General Electric Co. has developed a system whereby the dryer load is maintained constant, and the sheet tension is balanced by generator power put into the system. When a snap-off occurs and the tension disappears, the generator immediately drops its load and reverts to motor operation, while the dryer section continues to carry its normal load.

499. Flywheels.—The normal paper machine is so constituted that it has an extremely heavy inertia section in the middle (the dryers) and relatively light inertia sections on either end. This means that the end sections will respond much more quickly to voltage changes than the dryers; and, if speed changes in the machine as a unit are attempted too rapidly, the natural result is a broken sheet at either end of the dryer section. Though this may not cause any concern on constant-speed machines, it may be disturbing on machines where it is necessary to change the speed frequently for different grades of paper. In many installations, this difficulty has been obviated by the proper use of flywheels, and the right selection of motor for some of the lighter inertia sections.

HARLAND SECTIONAL INTERLOCK DRIVE

500. General Principles.—In the Harland interlock system, each section of the paper machine is driven by an adjustable-speed direct-current motor. Normally, the speed adjustment of the whole machine is obtained by means of armature-voltage control; but for machines with very wide speed range, a combination of armature voltage and shunt-field control is employed. Over a period of years, numerous improvements have been incorporated in the Harland drive, but the simple and well-tested principle of control by the mechanical differential has remained unchanged. A description of the general design will be given before outlining the characteristic features of the modifications.

501. Description of Typical Drive.—The general arrangement and layout of a typical Harland drive for a large newsprint machine is shown in Fig. 150. The direct-current adjustable-voltage generator G supplies the necessary power to the section motors A_1 to A_7. This generator is separately excited, and the exciter also supplies the excitation current to the field circuit of the section motors. In most cases, the motors are of medium speed and require single-reduction, enclosed, herringbone gears B to reduce the speed to that required by the driven section. For simplicity, no main switchboard is shown in Fig. 150; however, a main switchboard is provided between the generator and exciter and the main busbars DC and the exciter busbars EB. On the couch section is shown one of the motor starting panels F, with

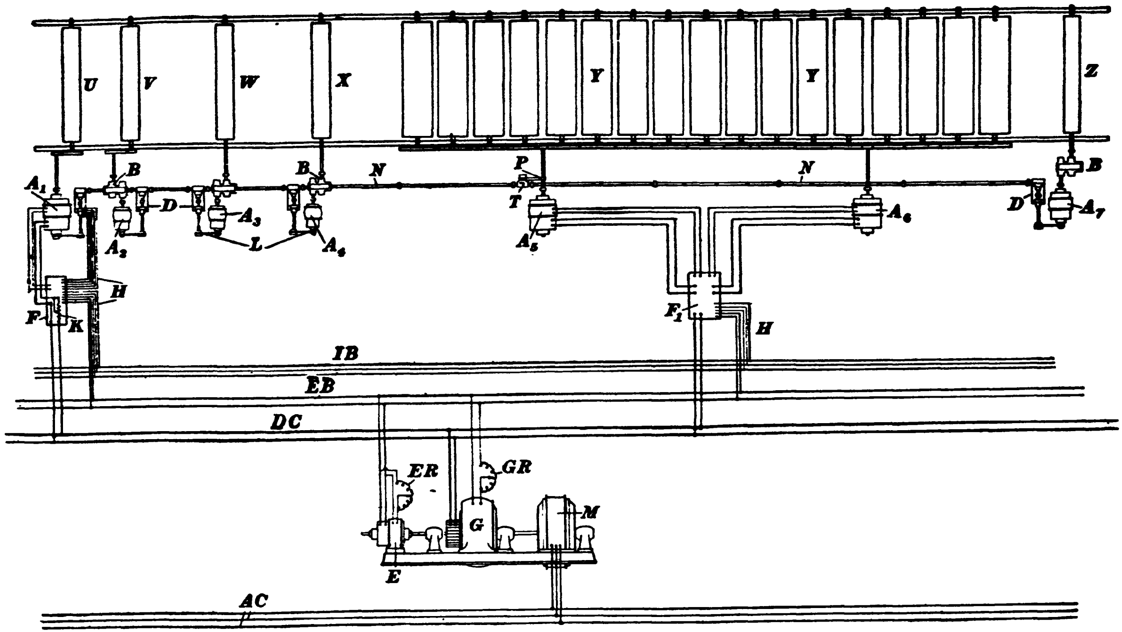


FIG. 150.

A_1-A_7. Section motors.
B. Speed-reduction gear.
D. Differential regulator.
E. Exciter.
F. Motor starting panel.
F_1. Dryer starting panel.
G. Direct-current generator.
H. Contact and field connections.
K. Armature starting resistances.
L. Cone pulleys and belt for adjusting draw.
M. Main synchronous motor.
N. Master shaft.
P. Chain drive.
T. Bevel gears.
U. Couch press.
V. First press.
W. Second press.
X. Third press.
Y. Dryer section.
Z. Calenders.
DC. Main d.c. bus, 500 or 250 volts.
EB. Exciter bus, 250 volts.
ER. Exciter field rheostat.
GR. Generator field rheostat.
IB. Interlock bus, 250 or 125 volts.
AC. Main a.c. bus.

the necessary connections from the field and armature circuits of the motor and differential regulator *D*. The corresponding starting panel for the dryer motors is shown at F_1.

502. Interlock Control System.—The arrangement of the interlock control system for the mechanically interlocked, or master shaft, drive is also shown in Fig. 150. It consists of a master shaft *N*, which extends the entire length of the variable-speed end of the paper machine. This shaft transmits practically no power, as it is only for control; but, in common with all other parts, it is made of ample size, so as to be capable of withstanding hard usage. At each section, the differential control gear *D* is inserted. The master shaft can be driven either by a small, separate master motor or from one of the sections of the paper machine, preferably the dryer section *Y*, as shown in Fig. 150. This drive consists of a small gear or chain drive *P*, with a bevel-gear box *T*.

The drive in which the differential is driven electrically is now generally preferred to the master-shaft drive; it is shown diagrammatically in Fig. 151. A master alternator *MA* is driven by a master motor *MM*, or by the dryers. In some cases, two such master alternators are supplied, as here shown, the second one, in this case, being driven by the section motor *A*. This master alternator is connected electrically to a small synchronous motor on the differential control gear *D*, and performs the same function as the master shaft. It is beneficial to use the dryers as the master section on most drives, in order to utilize the large fly-wheel effect of the dryer cylinders for steadying purposes in case of any frequency or other disturbance from some outside source. Where two master alternators are supplied, then, when the dryers are shut down, the synchronous motors on the differential control are switched over automatically from the alternator driven by the dryers to the alternator driven by the master motor *MM*. In this way, the speed of the machine, and the intersectional speed relation, is maintained constant, whether the dryers are running or not.

503. The Mechanical Differential.—A diagrammatic illustration of a differential-control apparatus, which is geared to the master shaft at each of the sections to be controlled, is given in Fig. 152. This differential control consists of bevel gear *P*,

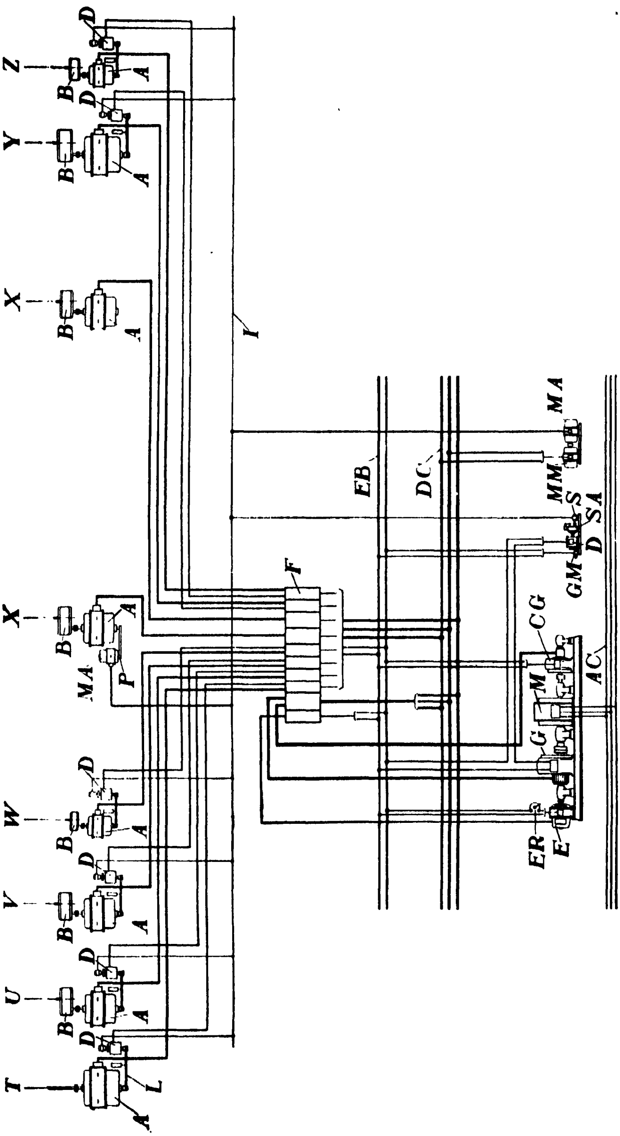


Fig. 151.

which is free to revolve on cone-pulley shaft S, and a bevel pinion Q, which is mounted on the master shaft R. Attached to the bevel wheel P are three planetary pinions L, which mesh with the sun wheel K, the last named being keyed to the cone-pulley shaft S; the pinions L also mesh with the internal teeth of the annular ring N, which turns freely on shaft S. Around the outside of the annular ring N are teeth that engage with another spur wheel O, mounted on shaft T, this shaft being connected through a coupling to a shaft carrying the brush arm D in the automatic differential regulator C.

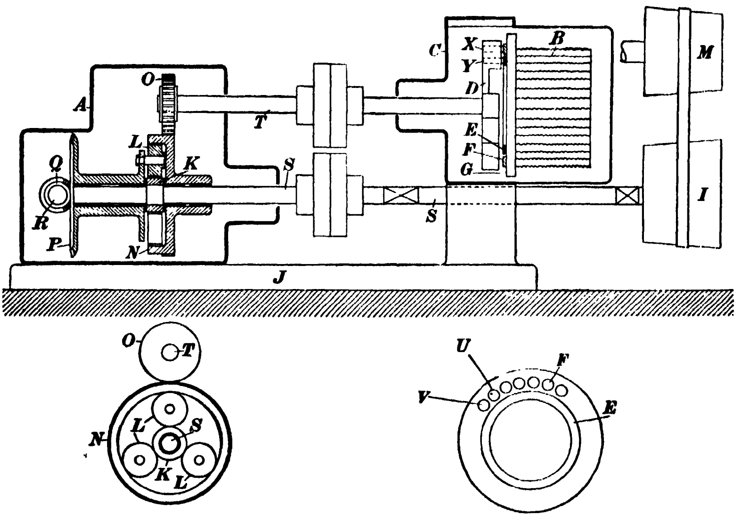


Fig. 152.

If the shaft S, carrying the cone pulley I, which is driven by the section motor, runs (in the opposite direction) at the same speed as the bevel gear Q, located on the master shaft, then there will be no resultant movement of the angular ring N; but, however little these two may vary in angular position relative to each other, a correct and instantaneous response is given on the annular ring N and, therefore, on the wheel O, which is driven by the annular ring. The bevel pinion Q is driven by the master shaft in each case, and the sun wheel K is driven through the cone pulley by the section motor itself, which must be controlled in each case. Therefore, any tendency to difference in angular

relation between the master shaft and the motor to be controlled is instantaneously reflected on the annular ring; the pinions cannot turn freely; they must either pull back or push ahead on the annular ring.

In the more recent drives, the master shaft is eliminated and a synchronous motor *T*, Fig. 153, drives one side of the improved mechanical differential, while the other side is driven by the cone pulley on the section motor *M*. (Note that parts in Fig. 153 that correspond to those in Fig. 152 are lettered differently.)

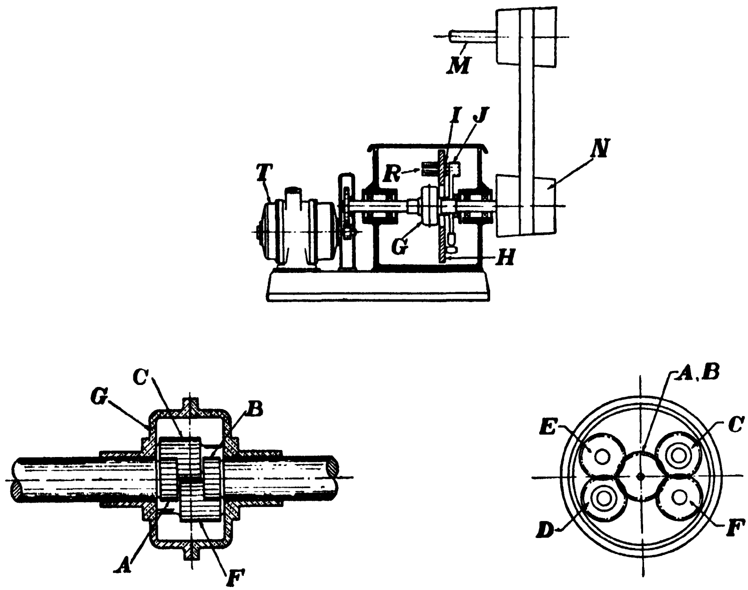


FIG. 153.

Thus the inconvenience of a master shaft running the length of the machine is eliminated, while the mechanical principle, with its rigid control, is retained. The two main gears *A* and *B* are formed integral with the respective shafts, and engage with planet wheels *C* and *D* and *E* and *F*, respectively; that is, wheel *A* engages with planet wheels *C* and *D*, wheel *B* engages with planet wheels *E* and *F*. The planet wheels engage with one another in pairs, *C* with *F* and *D* with *E*. Hence, according to the law of the differential, as long as *A* and *B* rotate in opposite directions, at exactly the same speed, the casing *G*, which carries

the planet-wheel spindles and the control brush arm J, will remain stationary in space. Any angular displacement of either shaft will instantly produce a proportional movement of

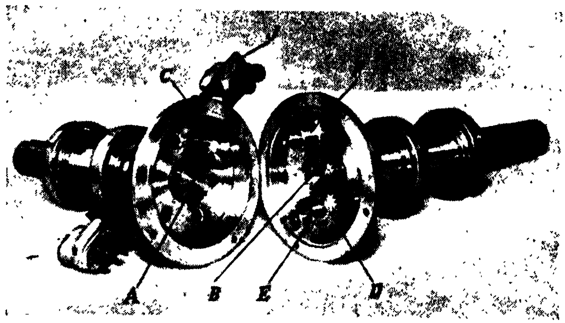


FIG. 154.

the casing and brush arm. Fig. 154 is reproduced from a photograph that illustrates the moving elements of the differential shown in Fig. 153, the casing G being opened up to show the

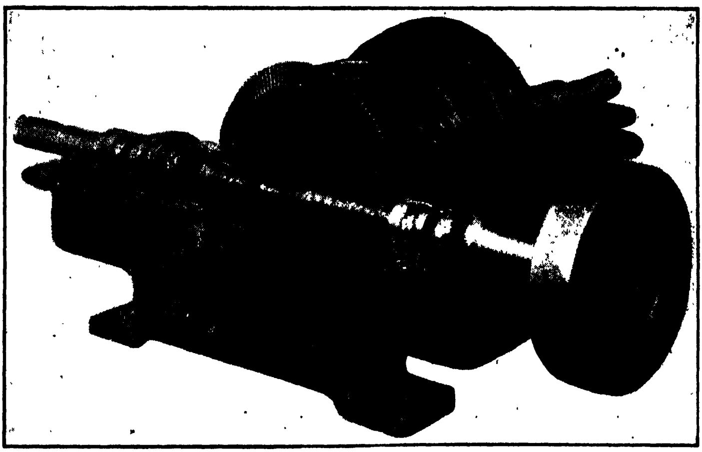


FIG. 155.

arrangement of the main gears and planet wheels. Fig. 155 is a photograph of the gear unit shown in Fig. 152.

These gears are cut exceedingly accurate; any part is interchangeable with any other corresponding part, and all machining is to within a limit of 40/10,000 inch. By this means, backlash is

eliminated, and it is claimed that more accurate control is obtained than is possible with any form of electrical differential.

504. The Differential.—Thoroughly to understand the action of this control, study the law of the differential. It will be found very helpful to build a small differential gear, which may be constructed as shown in Fig. 156. It consists of a small wooden frame C, with four small bevel gears D, D_1, D_2, D_3, all of the same size and having the same number of teeth. Gears D and D_2 turn on journals that are attached to the frame C; gear D_1 is keyed to a shaft at the other end of which is keyed the handle A; and gear D_3 is keyed to a shaft at the other end of which is

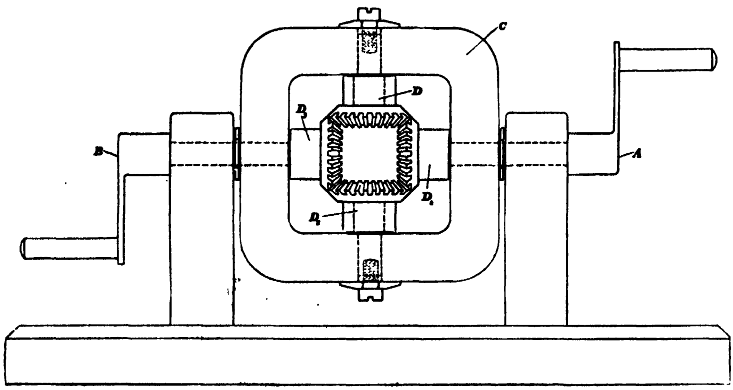


FIG. 156.

keyed the handle B; the wooden frame C is free to turn on these two shafts. Suppose the frame to be held stationary and handle A to be turned clockwise; then, gears D and D_2 will turn in opposite directions and will cause gear D_3 to turn in a direction opposite to that of gear D_1, which is keyed to the same shaft as the handle A. The two handles A and B will therefore turn in opposite directions at the same speed in revolutions per minute. Now, if the frame C be free to turn, and handles A and B, together with gears D_1 and D_3, are turned in opposite directions at the same speed, say 100 r.p.m., the frame C will remain stationary, the conditions then being exactly the same, insofar as the revolutions of the gears are concerned, as they were when the frame was held stationary. If, on the contrary, while A makes 100 turns, B makes 1 turn more or less than this, *i.e.*,

101 or 99 turns, the frame C must make half a turn forward or backward, the same result that would be had if D_1 were stationary and handle B made 1 turn. In other words, for this case, the angular displacement (angle between the initial and final positions of the frame C) is 180°. The angular displacement has nothing to do with time, it depends only on the difference between the number of turns made by the gears D_1 and D_3, regardless of whether this takes 1 minute or 1 year. Therefore, if in *any* period of time, gear D_1 has an angular displacement of 1° greater or less than gear D_3, the frame C must be displaced $\frac{1}{2}°$ from its initial position. This arrangement is called an **epicyclic train** or **epicyclic differential.**

505. The Differential Control.—The Harland system of control is merely the application of the foregoing principle to the regulation of the speed of the electric motor. Thus, in Fig. 152, if shaft R and shaft S vary 1° in angular displacement, the displacement of the annular ring N will be $\frac{1}{2}°$; and since the annular ring has twice as many teeth as the wheel O, keyed to shaft T, its displacement will be $\frac{1}{4}°$. It will thus be seen that any angular displacement of the master or control shaft gives a proportional displacement of the regulator-arm shaft T. In the same way, also, in the case of each individual section, any angular displacement of the paper-machine roll creates a proportional displacement of the differential regulator (brush) arm D. This applies also to Fig. 153. This ratio is sometimes termed the *mechanical ratio of the drive*, and it is a function of the paper-machine roll diameter and the speed at which the interlock differential is driven. This ratio varies slightly with different classes of paper machines, and must be taken into consideration when designing the drive.

It will therefore be seen that positive intersection control is obtained, in view of the fact that any tendency of the drive motor to change the roll speed must instantaneously produce a correction by means of the differential regulator arm D. This regulator arm moves over a faceplate containing a number of resistance units, B, Fig. 152, and in so doing cuts resistance in or out of the circuit in series with the shunt field of the motor to be controlled. In practice, the regulator arm quietly oscillates between two contacts, of which there are 80 to 100 on the face-

plate. The accuracy with which the desired speed is obtained is so great that if there were a thousand contacts instead of 100, they would not suffice to have one for every requirement in speed; the brush would still move between the contacts, one on each side of the desired speed. Referring to the lower right-hand part of Fig. 152, suppose that one of these contacts U represent 800 r.p.m. on the motor, that the next contact V represent 802 r.p.m., and that a speed of exactly 801 r.p.m. on the motor were required; then the brush arm D would be quietly breathing between the two contacts U and V, spending sufficient time on either contact to produce an average field that will give a perfectly steady motor speed of 801 r.p.m., the speed that was desired for the moment. Should this desired speed be 801.1 r.p.m., say, then the action is exactly the same as before, except that the arm spends a fraction more time on contact V than on contact U.

506. Draw Adjustment.—If the machine operator desire to change the draw between sections of the paper machine, he has only to move the belt on the cone pulley N, Fig. 153, and cone pulley M (attached to the motor shaft), which means that the motor is then trying to drive B at a speed different from that at which it was running before. This immediately sets in motion the casing G, which comes to rest again in a moment, after moving through a few degrees of arc, perhaps, but still enough to alter the resistance in R; harmony is then once more established, and the motor, though running at a different speed, as was desired, is still driving the pinion B at exactly the same speed as that of the pinion A. The 1½-inch belt may be shifted on the cone pulleys by a hand wheel, or, more generally, by remote control of a ⅛-hp. motor that operates the belt-adjustment gear.

If the load vary on any section, the motor will try to speed up or slow down, a change that would immediately make the pinion B try to maintain a speed different from that of the pinion A. The slightest difference in the angular velocities of B and A will move the casing G and cause the arm J to move in such a manner as to slow down or speed up the motor as much as is required to make the speed of A again the same as that of B. It should be particularly noted that the slightest difference in motor speed is reflected in the differential before an angular

movement of more than a few degrees has occurred, and this instantly introduces a powerful correcting force. Thus the speed is maintained at the desired point by positive mechanical means, this differential having no backlash or elasticity.

507. Starting Up.—The starting gear for the respective sectional motors in large machines is usually of the automatic type, having contactors (switches) operated by control stations on the front side of the paper machine, and so arranged that any section can be started, stopped, or inched.

Small machines are sometimes provided with a hand-operated drum controller; but they can, of course, be arranged with automatic control, in a manner similar to the larger newsprint machines. The control is entirely automatic; all the machine operator has to do is to start the several section motors, and the interlock apparatus is brought into action as the various sections reach the speed at which the paper machine is required to operate. Any section can be immediately stopped, and can be started up again, without interfering with any of the other sections. Any one motor can be run at crawling speed independent of the rest of the machine, all of which will continue to run at the predetermined speed. All this is obtained by simple automatic devices.

508. Separate Starting Generator.—The use of heavily rated resistances for starting and slow running, while satisfactory up to a certain point, has three defects: (*a*) The starting is necessarily somewhat jerky, depending on the number of contactors employed; (*b*) with a variable-speed machine using variable voltage, a resistance value that is correct for a given voltage cannot be correct for any other voltage; (*c*) a large amount of power must be dissipated in heat during the starting and crawling periods, particularly in the case of heavy sections, such as the dryers. Because of these defects, the system of reduced voltage for starting and slow running is preferable.

This latter method consists in having a *crawling generator*, in addition to the main generator and exciter. The crawling generator may be driven by the main prime mover, either a turbine or a synchronous motor; or it may be driven independently of the prime mover, thus permitting the paper machine to run during week ends at crawling speeds for washing-up purposes,

changing felts, etc., without running the prime mover. In this latter case, the generator will be driven by a squirrel-cage induction motor. This method is especially useful when a turbine is the prime mover, since the turbine and the steam plant can then be shut down entirely on Sundays.

For starting each section, its motor is first connected to the crawling generator, and one section, or all sections, can be run from this generator at crawling speeds. When it is desired to run the section up to full speed, the control handle is put in the RUN position, and the section motor is transferred automatically from the low-voltage crawling bus to the main running bus with resistance in series with the armature. This resistance is then cut out automatically, with a suitable number of steps to bring the section up to speed.

509. Machine-Speed Regulation.—Apart from the necessity of keeping each individual section in step, or at the same relative speed, as the other sections, which function is carried out and maintained by the master alternator acting through differential regulators, it is also essential to keep the speed of the machine as a whole constant at any predetermined speed. In the older type, this was done by means of two voltage regulators acting, respectively, on the main busbar voltage and on the exciter busbar voltage. However, this is not now considered sufficient, since, although the main voltage may be kept constant, a change in temperature or a change in load will alter the speed of the master section and, hence, the speed of the machine as a whole. To overcome this limitation, an additional control is now employed with the Harland drive, termed the **governor-lock control.** This unit comprises four pieces of equipment, Fig. 157, as follows:

A small synchronous motor *S*, a duplicate of the synchronous motors driving the differential regulators, provides the speed reference from the machine, and is supplied with current from one of the master alternators *MA*. This motor *S* drives one side of a differential unit *D* through a motor-operated speed changer *SA*. The rheostat of the differential is connected in series with the main-generator field. The other side of the differential is driven by a governed direct-current motor *GM*, which provides the fixed reference speed. This motor, by means

of a special governor incorporated in it, maintains a constant speed within one-half of 1 per cent, irrespective of any changes in load or applied voltage up to a maximum of $\pm 5\%$. This small motor is connected across the excitation bus and, by means of

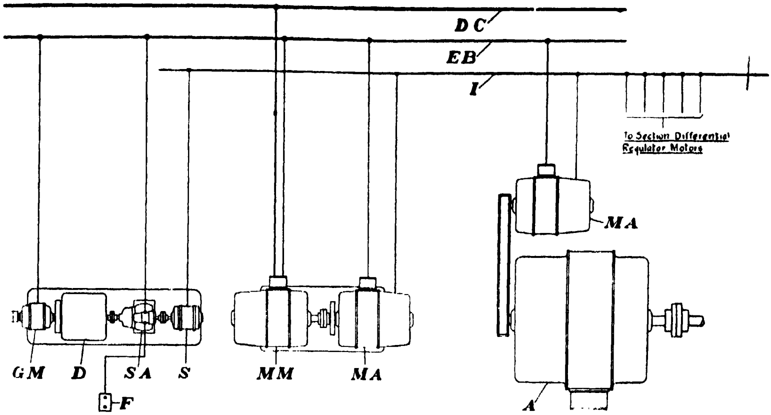


Fig 157.

its governor, maintains a constant speed, regardless of any change in conditions. For any set position of the change-speed gear, the two halves of the differential are constrained to run at

Fig. 158.

Fig. 159.

the same speed, by means of the differential action through the regulator arm in the main-generator field, which changes the main voltage until the motor driving the master alternator is running at the correct speed to give the load required by the

synchronous motor on the governor lock. In this way, the speed of the machine is controlled directly, and much better results have been obtained than by regulating the applied voltage. For altering the speed to any desired value, the change-speed gear is adjusted by means of a small motor, operated through push buttons, allowing the machine to be speeded up or slowed down, as desired.

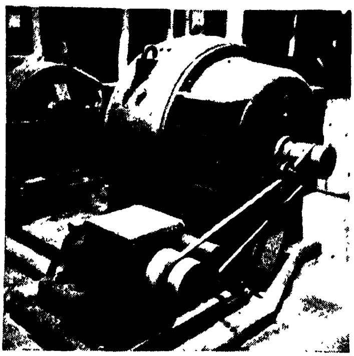


FIG. 160.

510. A Typical Drive.—A typical Harland drive is shown in Figs. 158 and 159. These reproductions from photographs show the wet and dry ends, respectively, of a Harland drive connected to a 262-inch newsprint machine, designed to operate at 1500 ft. per min. Fig. 160 shows a typical illustration of a Harland drive section unit. These pictures show the space-saving, neat, and safe condition of the back side of a machine equipped with sectional electric drive.

WESTINGHOUSE SECTIONAL ELECTRIC DRIVE

511. General.—In keeping with the advancement in the papermaking art, the Westinghouse Electric and Manufacturing Company has made many improvements in its sectional paper-machine drive during recent years. Though the principle of operation remains substantially the same, the methods of regulating and starting have been simplified and made more flexible; also, the arrangement of apparatus has been changed, with a view to compactness, reduction of parts, ease of maintenance, and better appearance. The resistance method of starting has been superseded by a two-generator system, consisting of a 'running' and a 'starting' generator. Further, the older forms of automatic speed regulation have been replaced with the present carbon-pile type. Since several installations of the older types of drives are still in operation, a brief description of these follows.

512. Older Forms of Drive.—Both the old and new forms of the sectional paper-machine drive employ individual direct-

current motors to drive each section of the machine. Power to operate these motors is obtained from a variable-voltage direct-current generator. The variable-voltage feature provides the over-all speed control for the paper machine. For starting, resistance is inserted into the armature circuit of the section motor, the resistance being shorted out (cut out) in steps, to accelerate the section. For slow operation, commonly referred to as *inching*, the resistance is retained in the circuit. Complete operation, including starting, stopping, and speed control, is accomplished automatically, the particular operation being initiated by the appropriately marked push button.

A regulating system provides the automatic speed control for the individual section motors. The older forms of speed regulators have been modified from time to time to improve their performance. The earlier types operate on a principle of intermittent make and break of contactors to short out of, or insert resistance into, the field circuit of the section motors. This action was first performed by a pair of contactors and a motor-operated rheostat, the operation of which was initiated by an electric speed differential. This form was later replaced by a rotary-contactor method, which consists of a master and a section rotary contactor, interconnected with the field resistor, so that the resistor is inserted into the circuit or shorted out, depending on the relative positions of the two rotary contactors. When the contactors are rotating in phase, the resistor is shorted and the motor field is fully excited. If the section motor is slowed down—shifting the contactor a small amount—the resistor is in circuit for a short period during each revolution, and the average field current is reduced; consequently, the motor speeds up and again operates in phase with the master contactor, the resistor being simultaneously cut out of the circuit.

A later type of rotary contactor utilizes a mechanical differential to shift a drum contactor axially under a set of brushes. The rotary movement of the drum makes and breaks the circuit, and the axial position of the drum under the brushes determines the length of open or closed period. The differential that shifts the drum is actuated by a synchronous motor and by a section motor, so that a change in the section-motor speed will cause the drum to shift axially in the direction that will change the motor field current to correct for the speed difference between the

section motor and the master synchronous motor. This form of regulator was superseded by the *carbon-pile* regulator.

Voltage regulators of the vibrating type were provided for maintaining constant generator and exciter voltages. The new installations employ the electronic type of voltage regulators.

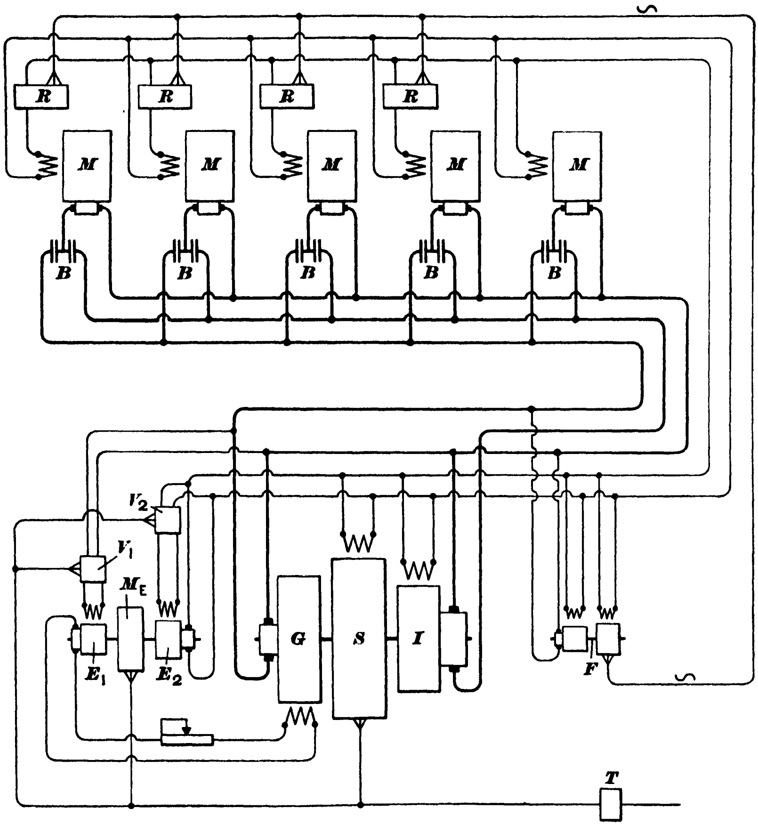


Fig. 161.

513. Modern Form of Drive.—The improved Westinghouse sectional paper-machine drive utilizes individual direct-current motors *M*, Fig. 161, for each section of the paper machine—couch, presses, dryers, calender, and reel. Power is supplied to these direct-current motors by a main generator *G*, which is driven by synchronous or induction motor *S*, forming part of a motor-generator set; or the generator may be driven by a turbine

or steam engine. The speed range of the paper machine is obtained by adjusting the voltage of the main direct-current generator over a voltage range corresponding to the paper-speed range. The section motors are separately excited, and their speeds are therefore substantially proportional to the direct-current voltage applied. The section motors are coupled to the intake shafts of the machine through enclosed self-contained high-efficiency gear units. The speed relation between the various sections of the machine is obtained by proper adjustment of the shunt fields of the section motors.

A three-unit exciter set, consisting of a motor M_E, Fig. 161, and a small exciter E_1 and a large exciter E_2, supplies excitation to the synchronous motor S, main generator G, inching generator I, section motors M, and control equipment. The small exciter E_1 provides excitation to the main generator only, the large unit E_2 providing to the rest of the equipment. The voltage of the large exciter is maintained at a constant value by means of an electronic voltage regulator V_2. A second regulator V_1 serves to maintain the voltage of the main generator by control of the small exciter that supplies excitation to this generator.

Each section motor is provided with an individual waterproof push-button control station B, with *start*, *stop*, *inch*, and *lock-safe* buttons. A master push-button station is provided with *stop*, *fast*, and *slow* buttons. These stations may be located at convenient positions on the machine; they give the operator complete control of each section, as well as of the paper machine as a whole. The 'lock-safe' button, when locked, renders it impossible for anyone to start up the section until unlocked with the key; this prevents possible injury to employes, or to the machine, by accidental or unauthorized starting.

To start or inch any section, a separate direct-current generator, driven from the main set or with separate drive, is provided. When a section is being inched, the motor is connected to the inching generator I, which normally operates at low voltage, and which has been adjusted to give the desired inching speed, by depressing the 'inch' button on the section-control push-button station. The section may be inched repeatedly, or operated at low speeds for long periods of time.

When a section is being started, the motor is first connected to the inching generator; at the same time, a motor-operated

rheostat in the field of this generator raises the voltage, which causes the section to accelerate smoothly to the desired operating speed. When the voltage of the inching generator becomes equal to that of the main generator, the section motor is automatically transferred to the main generator. As soon as the transfer is complete, the motor-operated rheostat is returned to its original position. The control is fully automatic, the complete starting operation being obtained by pushing the 'start' button of the section push-button station. The speed of the entire machine

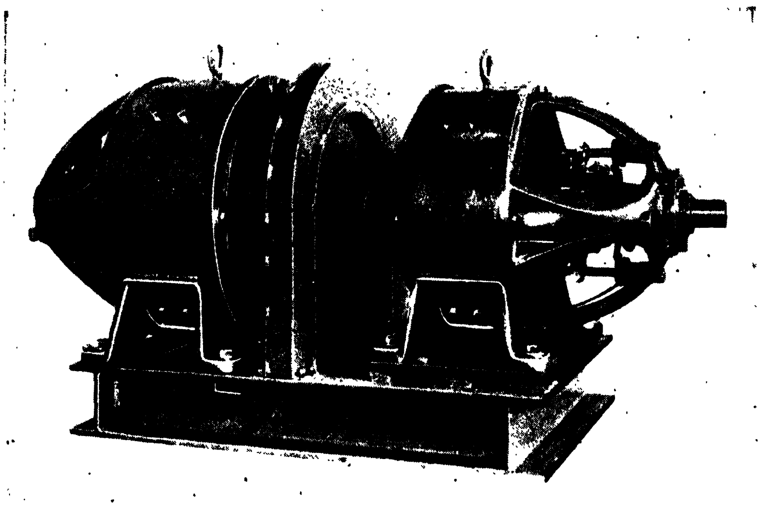


FIG. 162.

may be adjusted from the master push-button station. This push button controls the operation of a motor-operated rheostat, with circuits in the field of the main generator, and in the control circuit of the voltage regulator.

514. Speed Control.—To maintain proper speeds on the various section motors regardless of transient conditions, such as variations in load or surrounding temperature, the equipment is provided with an extremely sensitive regulating system. This includes a master frequency generator set *F*, Fig. 161, which supplies an alternating current for speed reference, and an individual section-speed regulator *R* for each section of the machine.

515. Master Frequency Generator Set.—The master frequency generator set, Fig. 162, consists of an alternating-current generator driven by a master direct-current motor. This generator provides power for driving small pilot synchronous motors, Fig. 163, of the individual section-speed regulators. These pilot motors are all driven at a speed that is determined by the frequency of the alternating-current generator. The master motor receives its power from the main direct-current generator, and operates at a speed proportional to the generator voltage. The alternating-current generator thus operates at a frequency proportional to the main generator voltage, and all the pilot

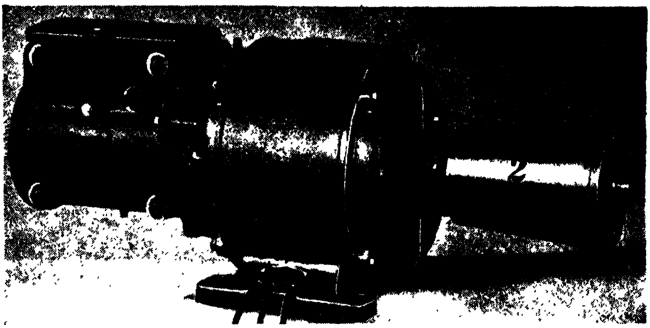


Fig. 163.

synchronous motors operate at a speed corresponding to this frequency.

516. Individual Section-Speed Regulators.—The individual section-speed regulator consists essentially of the following parts: a small pilot synchronous motor, Fig. 163, a mechanical differential, a carbon-pile regulator panel, and a cone-pulley speed changer with belt shifter, all mounted on a common bedplate. The pilot synchronous motor has a double-extension hollow shaft; one extension supports the mechanical differential, with its accompanying regulator panel; the other extension supports one cone pulley of the speed changer. The second pulley is mounted on separate bearings, and is equipped with a sprocket for chain drive from the section motor.

Corrective differential action of the section-speed regulator is obtained because one end of the mechanical differential is driven by the small synchronous motor at a speed corresponding to the

frequency of the master set, while the other end is driven by the section motor, through the speed changer, at a speed corresponding to that of the section. Each carbon-pile section-speed regulator automatically functions, through the corrective action of its mechanical differential, to adjust the excitation of the section motor so it will maintain uniform speed in direct relation to the speed of the master frequency generator set. In this manner, the direct-current section motors are made to operate as synchronous machines, and permit only slight phase displacement between their operating speed and the corresponding speed of the master set. Adjustments in speed can be made on

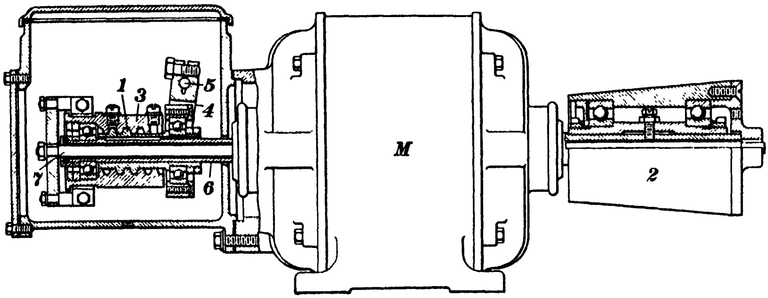


FIG. 164.

any individual section by adjusting the position of the belt on the speed changer.

517. The Mechanical Differential.—The mechanical differential is shown in the simplified outline diagram, Fig. 164, and consists of a worm-and-nut unit. The pilot synchronous motor *M* drives the worm 1, which is keyed to the motor shaft *S*, but is free to slide in and out along the shaft. The cone pulley 2, through its shaft 7, drives the nut 3, which engages the worm. This drive is accomplished through the hollow shaft of the motor: the nut is restrained from moving in a longitudinal direction. So long as the motor and pulley are revolving at the same speed, there will be no relative motion between the worm and nut; however, if either the motor or the pulley advance one on the other, the worm revolves relative to the nut, and causes itself to be moved in or out along the shaft. This movement is transmitted by a yoke lever 4 as a turning force to the output shaft 5,

which actuates the speed regulator. Part 5 is also shown in Fig. 163.

518. Carbon-Pile Speed Regulator.—The carbon-pile speed regulator, Fig. 165, consists of a stack of thin carbon disks 1, connected as resistance in the field circuit of the section motor. A compression of the stack decreases the resistance of the pile and allows more current to flow through the field winding;

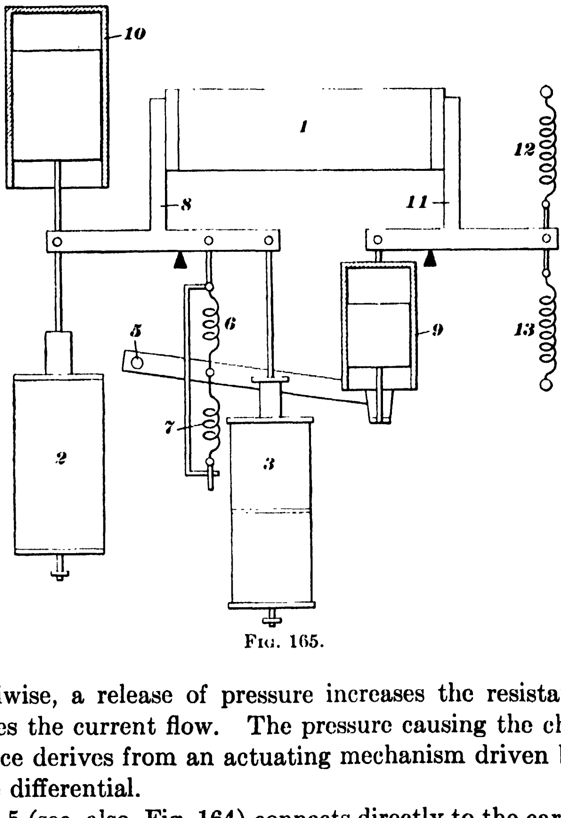


FIG. 165.

contrariwise, a release of pressure increases the resistance and decreases the current flow. The pressure causing the change in resistance derives from an actuating mechanism driven by shaft 5 of the differential.

Shaft 5 (see, also, Fig. 164) connects directly to the carbon-pile actuating mechanism. If the relative speed between the nut and worm changes slowly, shaft 5 will rotate slowly and set up stresses in springs 6 and 7, causing lever arm 8 to compress or open the carbon pile. The dash pots 9 and 10 will have only a negligible effect during slow changes. If the speed change is

rapid, the dash pot 10 will prevent lever arm 8 from operating, the movement being absorbed in springs 6 and 7. However, under these conditions, the movement transmitted through dash pot 9 will cause lever arm 11 to compress or open the pile.

Following this rapid adjustment of the carbon-pile pressure by the lever arm, the springs 6, 7, 12, and 13 will relieve their stresses by transferring the adjustment from lever arm 11 to lever arm 8. The left-end coil 2, a field coil, is so connected that its pull is proportional to the field current, and the right-end coil 3, an armature coil, is so connected that its pull is proportional to the armature current. An instantaneous load on the section motor would normally cause the motor to slow down momentarily; the regulator would quickly release the pressure on the carbon-pile and decrease the field current so as to increase the speed of the motor. If the load has been removed, the motor will overspeed momentarily, and consequently tend to 'hunt.' The armature and field coils 3 and 2 are connected to oppose the regulator action. Their pull changes as soon as the field or armature current changes, which is slightly in advance of the speed change of the motor; as a result, they anticipate the regulator action, and instigate opposing action to a lesser degree, their damping effect resulting in the elimination of all hunting of the section motor.

519. Remote Draw Adjustment.—The adjustment of draw between sections is readily made from the front side of the paper machine. This is accomplished by means of a pair of small synchro-tie or wound-rotor induction motor units, furnished as standard equipment and applied to each regulated section. One of these units is mounted on the front side of the paper machine. This unit is provided with a small dial handle on its shaft. The second unit is mounted on the section-speed regulator, and serves to shift the belt on the cone pulleys of the speed changer.

These synchro-tie units have their primaries continually excited from a low-voltage alternating-current single-phase source, and their three-phase secondaries are electrically interconnected. Normally, both units remain motionless. When the operator wishes to make an adjustment of draw, he turns the dial on the unit mounted on the front side of the machine, which causes the rotor of the unit on the speed changer to turn

an equal amount, thus adjusting the belt position and the speed of the section.

520. Slack Take-Up.—In order to overcome wrinkles caused by slack in the sheet between sections on the dry end of the machine, it is necessary momentarily to speed up one or more of the sections, to move it forward in angular displacement a sufficient amount to take up the slack in the paper. This result may be obtained by means of the *slack take-up*, or phase-advancer, equipment, which can also be applied to eliminate the slack between calender sections.

521. Core-Type Reels.—When a core-type reel is employed on the paper machine, it is necessary to adjust the speed of the in-driving shaft of the reel to compensate for the changing diameter of the paper reel from an empty to a full reel. With machines using this type of reel, the Westinghouse drive may include for this section an individual adjustable-speed direct-current motor, with suitable gear reduction, similar to the driving unit on the other sections of the machine. The control for this section is similar to that of the other sections; however, the differential type of speed regulator is not used. In place of this, a dynamic vibrating type of relay is used for automatically adjusting the excitation of the reel-section motor, so as to maintain constant armature current at all operating paper speeds. This results in substantially uniform tension in the sheet between the calender and reel from an empty to a full reel.

522. Individual Drive for Wet End of Cylinder Machine.—Through application of individual motor drive to the cylinder molds, suction rolls, and the primary and baby presses of the cylinder machine, the useful life of the wet-end felt is greatly increased. With the modern form of auxiliary wet-end drive, direct-current geared motors, having the proper reduction ratio and output speed, are applied. The driving units may be coupled direct, or be connected through a chain drive, to the in-take shafts of the various sections. The gear motors are arranged for separate excitation, and are designed to operate over the required speed range by armature voltage control with fixed shunt-field adjustment. To meet the operating requirements, the motors are designed with an inherent 'drooping speed-load characteristic,' so that they will automatically

adjust their operating speed to any slight variation in speed of the felt or to changes of roll diameter under pressure, without materially changing the torque or driving effort that they

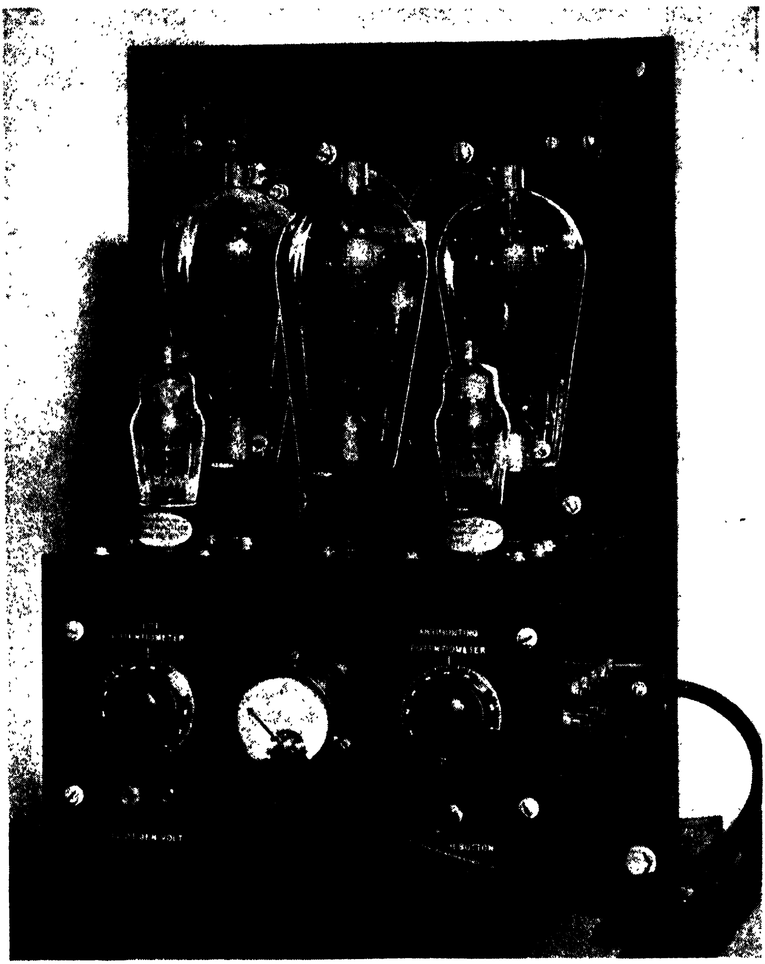


FIG. 166.

develop. This inherent characteristic of the properly designed direct-current motor makes it very suitable for this application.

The motors applied to the wet-end auxiliary sections are thoroughly protected against water by using either totally

enclosed forced ventilation or splash and drip-proof designs. The auxiliary drive motors are arranged to receive their power from the generator that supplies power to the main section of the machine, and are operated in parallel with the first main-press section motor.

523. Electronic Voltage Regulator.—The electronic voltage regulator, shown in Fig. 166, is essentially a controlled rectifier. Alternating current is rectified to produce direct current to excite the field of the exciter being regulated. The amount of current supplied to the field is continuously and automatically adjusted to maintain the voltage of the exciter at a constant level. Such a regulator is very sensitive and has no moving parts; consequently, it is claimed to have a much more rapid response than the older mechanical types.

BRITISH THOMSON-HOUSTON ALTERNATING-CURRENT DRIVE

524. Operation of Drive.—The British Thomson-Houston Company, Ltd., has developed an alternating-current sectional drive with selsyn control. The drive operates according to the speed-matching principle, the speed of each section driving an alternating-current commutator motor being controlled by a selsyn system. The motor speed is matched against a master speed, and any difference in the two speeds causes a selsyn to move the speed-regulating spindle of the alternating-current commutator motor to correct for the speed difference.

Selsyns are similar to wound-rotor induction motors, and in order to understand the operation, two similar three-phase induction motors should be considered as being connected to the same supply. Provided the rotors are in correct phase position, the rotor slip rings can be paralleled at standstill, so that no current will flow in the local circuit comprising the rotor windings and interconnections. If one rotor is now moved, the voltage generated in the rotor winding of this machine will not be balanced in phase by the rotor voltage of the other machine; consequently, a resultant voltage will exist in the local circuit, and this will cause a current to flow and a torque to be exerted by the two machines.

If one motor is driven, the other will follow it, and will run at exactly the same speed, provided the pull-out torque is not

exceeded. The two induction motors are said to be selsyn connected, the first induction motor being called the *transmitter selsyn* and the second the *receiver selsyn.*

525. Differential Operation.—If another suitably designed induction motor is connected between the slip rings of the transmitter and receiver selsyns, so that its stator is connected to the rotor of the transmitter and its rotor is connected to the slip rings of the receiver, the system will operate differentially. Provided the connections have the correct phase rotation, any one of the three machines will rotate at a speed equal to or equivalent to the speed difference of the other two. This third machine is called the *differential selsyn.*

526. Arrangements of Selsyns.—Three-phase alternating-current commutators with shunt characteristics, suitably designed for covering the whole speed range of the paper machine, are used for driving the various sections. A master selsyn is used as a common transmitter for all the receiver selsyns, which are coupled to the individual brush-shifting spindles of the section-driving alternating-current commutator motors.

Each receiver or brush-gear selsyn is supplied from the master through a differential selsyn, which is mechanically coupled to the section driving motor. If the differential selsyn does not run at the same speed as the master, the brush-gear selsyn rotates and regulates the speed of the alternating-current commutator motor in such a way as to bring the speed of the differential selsyn back once more into correspondence with the master selsyn speed.

The master and brush-gear selsyns are excited single phase from the same phase of the supply and the excitation that is supplied to the stator of the master machine and to the salient poles of the receiver selsyns.

The diagram, Fig. 167, shows the electrical connections for two sections of a paper-machine drive with selsyn regulating gear. Each section driving motor 1 is fed from the main supply busbars 2 through the slip rings 3, and is mechanically coupled through a variable ratio P.I.V. gear[1] 5 to a differential selsyn 6. The differential selsyn is, in turn, electrically connected to the brush-operating or receiving selsyn 7, which is excited from the

[1] A recently developed type of mechanical speed changer (see Art. 451).

main supply busbars 2. The rotor of the differential selsyn is connected to the selsyn busbars 8, which are supplied from the master selsyn 9. An alternating-current commutator motor 10 drives the master selsyn, and these two machines form the master speed-control set. The brush-operating selsyn 7 is coupled by means of a chain drive to the brush-shifting spindle 4 of the section driving motor 1.

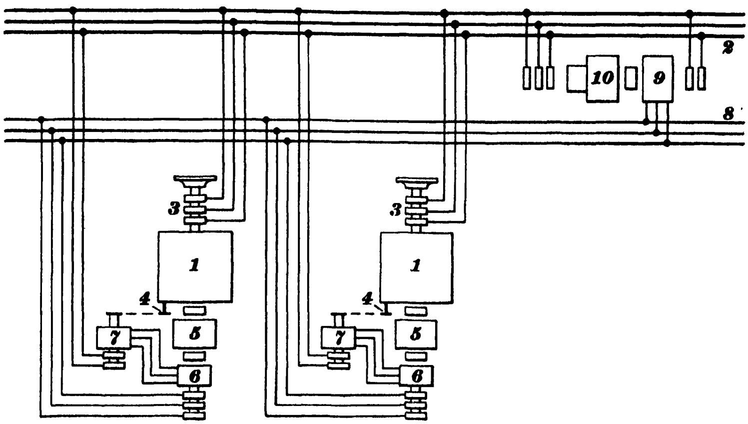


FIG. 167.

527. Speed Regulation.—If the section driving motor does not drive the differential selsyn at the same speed as the master selsyn, the brush-operating selsyn 7 moves the brush-shifting spindle of the section driving motor in such a direction as to correct the speed error. If the motor speed falls, the brush gear is moved in a direction to increase the speed of the section driving motor, and the rate at which the correction is made is proportional to the difference in speed between the section and master speeds.

528. Adjustment of Draw.—If it is desired to alter the speed of one section relative to the others for the purpose of varying the draw between sections, the ratio of the P.I.V. gear is altered, thus changing the speed of the differential selsyn relative to the alternating-current commutator motor to which it is coupled. If it is desired to increase the draw between one section and a preceding section—that is, to increase the speed of the section under consideration—the P.I.V. gear ratio must be altered so that

the speed of the differential selsyn becomes lower than that of the master. The brush-gear selsyn will then rotate, moving the brush gear of the alternating-current commutator motor and raising its speed until, once more, the master and differential selsyns are running at exactly the same speed. This change of gear ratio of the P.I.V. gear can be accomplished by hand, or by means of a pilot motor mounted on top of the gear box.

529. Adjustment of Paper Speed.—The speed of the paper machine as a whole is adjusted by varying the speed of the speed-control set. An increase of the speed of the master set causes the master selsyn to run faster than all the differential selsyns; consequently, all the brush-operating selsyns move the brush gear of their associated motors, causing each section to accelerate by an equivalent amount.

530. Section Driving Units.—The design of each section driving unit is very compact and neat, each unit consisting of a main gear, alternating-current commutator motor, P.I.V. gear, and differential selsyn, mounted on a combined base plate. The brush-gear selsyn can be conveniently placed at the side of the section driving unit, or it can be mounted on the end shield of the alternating-current commutator motor. The selsyns and P.I.V. gears being totally enclosed, the equipment is particularly suited to paper-mill conditions.

The regulating equipment takes no part in the actual driving of the section, the function of the regulating gear being to set a standard of speed and to adjust the brush gear of each section driving motor to make it conform to the standard set. The correction of speed is so rapid that, when once the motor has been brought to the correct speed, only slight movement of the regulating spindle takes place, any tendency for the speed to change being checked at once.

The P.I.V. gears form a very accurate and robust method of regulating the draws between sections. The load is extremely light, the power to be transmitted by these gears is very small, and the power used for regulation is practically negligible.

PAPERMAKING MACHINES

(PART 6)

EXAMINATION QUESTIONS

1. (*a*) Why is it necessary to drive some parts of a paper machine at constant speed and other parts at adjustable speeds? (*b*) To what parts does each drive apply?

2. (*a*) Why have change gears been superseded by cone pulleys for changing the speed of the variable-speed shaft? (*b*) Explain the principle of the cone pulley.

3. (*a*) Explain the manner in which a friction clutch acts. (*b*) How should it be thrown in?

4. Mention two important differences between the Marshall train and the rope drive.

5. Compare the English and American systems of threading a rope drive.

6. What is meant by (*a*) the slip of a belt? (*b*) the creep of a belt? (*c*) How is the making of paper affected by slipping and creeping of belts?

7. Describe the loose-belt drive and state why it is used and where.

8. What is the difference between spiral bevel and hypoid gears, and when should they be used?

9. Give four reasons for favoring the sectional electric drive.

10. Explain why direct-current motors are so extensively used for driving paper machines.

11. What are the important features in the operation of synchronous motors and generators?

12. Explain the rheostatic system of controlling, stating the object of it and how it works.

13. (*a*) What is the purpose of the differential gear? (*b*) Select one form and explain how it works.

14. Select one type of sectional electric drive and explain how you would change the draw on any section.

15. To what extent is the paper stretched between the couch rolls and the reel? State how it is stretched, and why.

16. What is the essential difference in the principle of speed control of a direct-current motor drive and the alternating-current motor drive of the British Thomson-Houston arrangement?

17. What is the source of the steam used for drying the paper when the various types of prime movers are considered?

SECTION 2

HANDMADE PAPERS

BY DARD HUNTER

APPARATUS AND DETAILS

THE MOLDS AND THE DECKLE

1. Preparation of Pulp.—In the making of paper by hand, the preparation of the pulp[1] (except for special kinds of watermarking, which will be described later) is precisely the same as that used in the very finest machine-made papers. The pulp should be made from a mixture of new linen and cotton cuttings, slowly boiled in stationary boilers; the fibers should be well drawn out in the beater, and should not be minced by rapid or close beating. It is possible to make handmade sheets from almost any kind of pulp; but, owing to the expensive labor cost and the great length of time needed to make these *vat* papers, only the best materials should be used.

In order that the explanation of the process of making paper by hand may be the more easily understood, a description of the appliances used will first be given.

2. The Mold.—The molds and the deckle constitute the principal feature of the appliances used in the process of making paper by hand. The **molds** are used to convert the watery, fibrous liquid that contains the pulp into sheets of even size and thickness.

These molds are rectangular-shaped frames of wood, the upper side being covered with woven wire that will hold the pulp and, at the same time, allow the water to drain through, in a manner similar to the action of a sieve. The **deckle** is a light wooden structure, which fits over the mold on all four sides like a picture

[1] By *pulp*, the author here means stock.

frame; it determines the size of the sheet and keeps the pulp from running over the sides of the mold. A top view of a laid mold, with the deckle in place, is shown in Fig. 1.

The molds are made of mahogany, about five-twelfths of an inch in thickness, constructed not unlike a very shallow, rectangular box, but without top or bottom, joined at the corners as

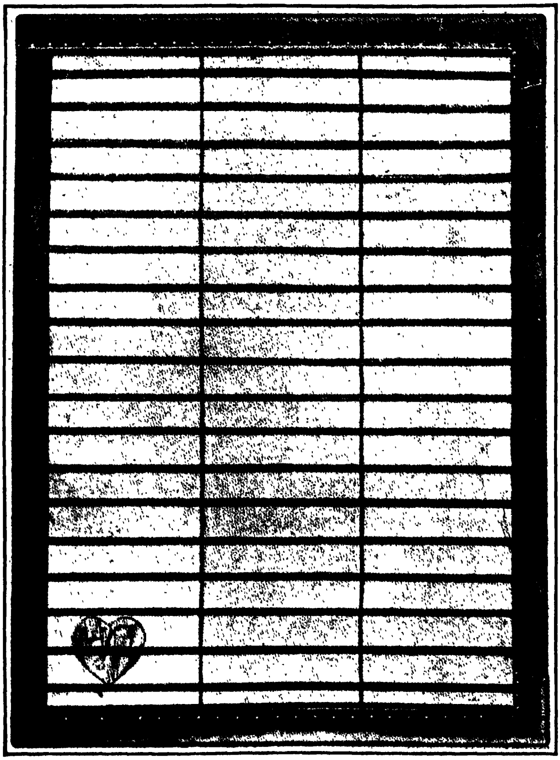


FIG. 1.

shown in (*c*) and (*d*), Fig. 2, the ends dovetailing into each other. The sides that make up the frame are rounded, on the under edges, as indicated in (*e*) and (*f*), Fig. 2. The frame is bound at the corners with brass strips, screwed to the wood, as shown in (*c*), Fig. 3.

Running across this rectangular frame from one long side to the other are wooden ribs, the tops of which are flush with the

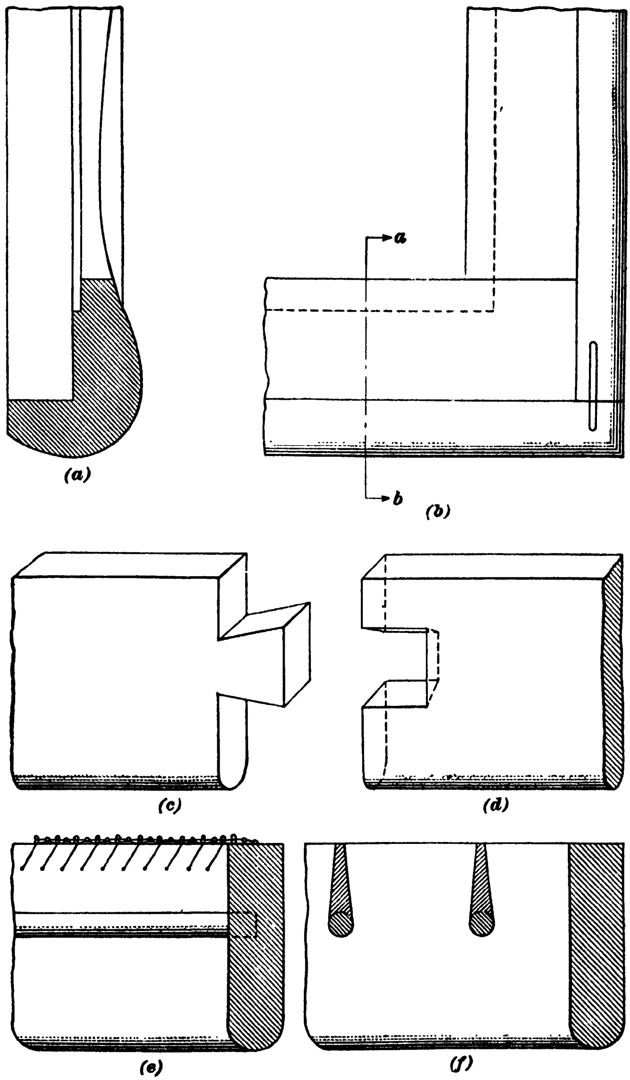


FIG. 2.

top of the mold, and about one and one-eighth inches apart.[1] The ribs have a wedge-shaped cross section, which causes a

[1] The distance between the chain lines in the paper determines how far apart these ribs must be spaced, since each chain line is supported by a rib. In *antique laid*, the wooden ribs and chain lines run from one to two inches

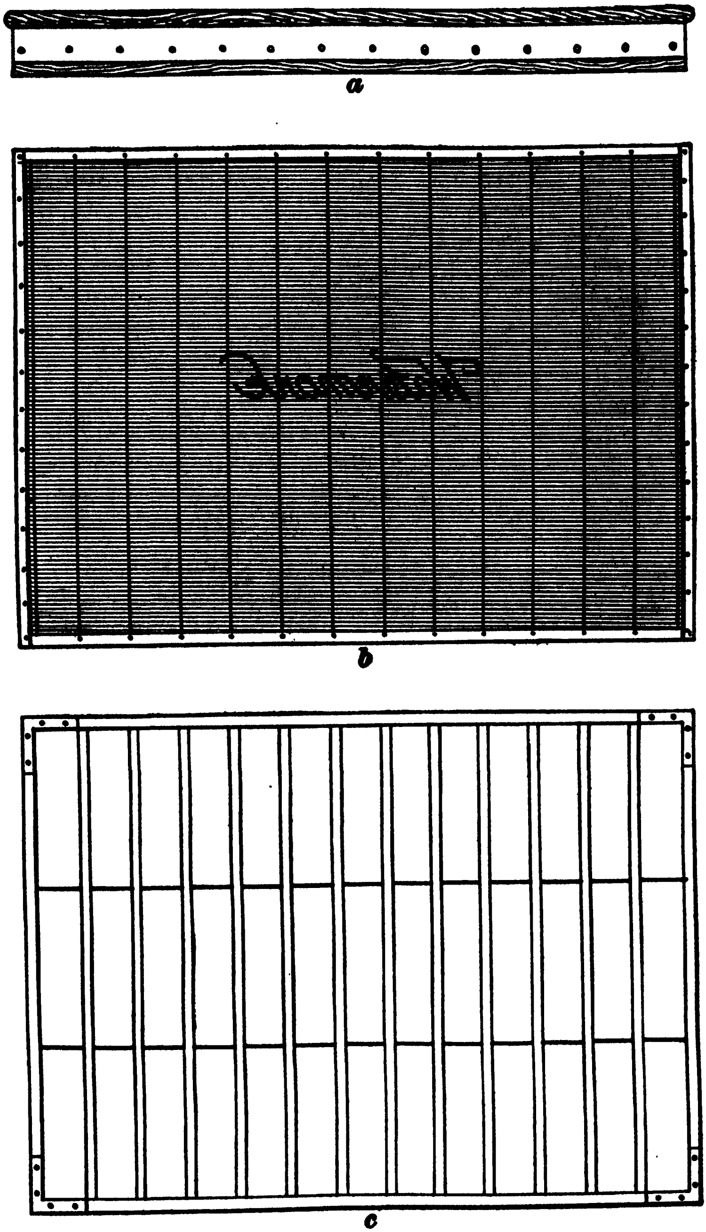


Fig. 3.

suction that acts on the top face of the mold when it is lifted from the vat. The ribs are fastened to the frame of the mold by small, round projections on their ends, which fit into holes bored into the frame. Fig. 2 (*e*) shows a side view of one of these ribs, and Fig. 2 (*f*) shows an end view of two of them. (It may here be remarked that all views in this figure, and in all other figures of this subject, have been drawn according to the first-angle method of projection.) Note that the thick, or lower side, of these wedge-shaped ribs is rounded. The ribs stand so that their center lines are perpendicular to the faces of the frame, and the wide edge is down. This makes the *opening* between the ribs smaller at the bottom than at the top; and when the frame is raised vertically upward through the liquid, this construction causes more of the liquid to be lifted than flows immediately through the opening, the result being that a partial vacuum is left behind, which causes a slight suction. The ribs are braced by heavy brass bars, running through them lengthwise of the frame (from one short side to the other), as shown in Fig. 3 (*c*).

After the wooden parts of the mold have been completed, with frame, ribs, and fastenings in place, the **wire covering** that holds the pulp is added. This covering may be either *laid* or *wove*, since the woodwork is the same for either. For making a **laid mold,** see Fig. 3 (*b*), the first covering of wires added to the mold[1] is a backing of wires averaging about nine to the inch. The heavier wires of this backing run the long way of the mold (from left to right, as the mold is held in the hands of the vat-man). Before this backing is added to the wooden frame of the mold, it is stitched together with finer wires running in a direction at right angles to that of the heavier, lengthwise-running wires; and these finer wires are so spaced that each falls directly over one of the wooden ribs. After the backing is applied, the laid wires are added. These wires are woven in the same manner as the

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apart, but in most modern molds, they are about one and one-eighth inches apart.

[1] In the early molds, the top covering was bound directly to the ribs, without the backing wires, which caused a dark line to appear on either side of the chain line in the finished paper. This was overcome in the late eighteenth century by using backing wires to raise the covering from the ribs. The dark lines in the paper were caused by the pulp lying heavier at either side of the chain lines when they were close to the supporting ribs. All paper showing these mottled stripes is called *antique laid*. Fig. 1 shows an antique-laid mold, while a modern-laid mold is shown in Fig. 4.

backing, but the laid lines (heavier wires) are closer together, averaging 22 to the inch in an ordinary mold. The two coverings, the latter on top of the former, are stitched with fine wire to the ribs, which are pierced for this purpose, as indicated in Fig. 2 (*e*). The ends of these wires are fastened with small copper

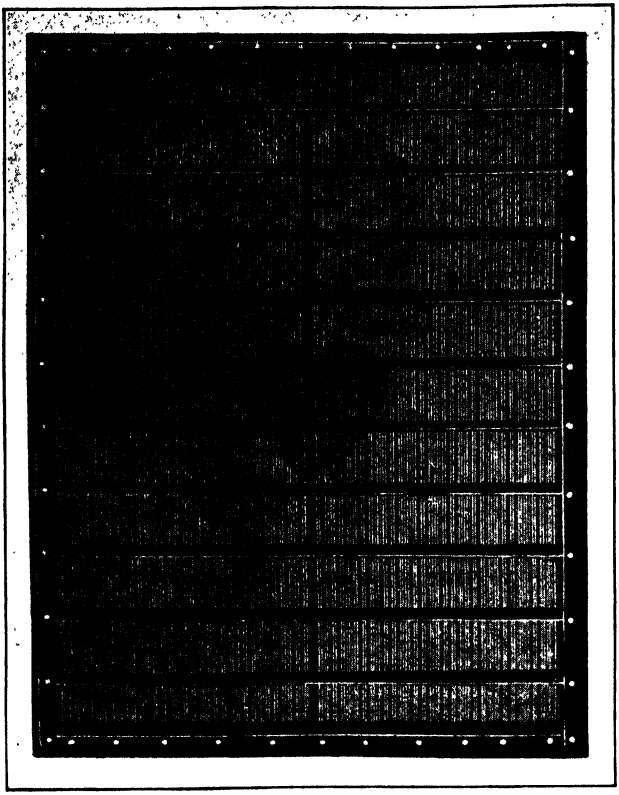

Fig. 4.

nails at the four edges on the outer part of the frame, the whole edge being bound with a narrow strip of copper, which secures the free ends of the wires. A finished mold is shown in Fig. 3 (*b*).

3. In a **wove mold,** Fig. 8 (*b*), the covering[1] is finely woven brass wire, made in the same manner as screening, only more

[1] All paper before 1750 was laid, since it was not until that year that John Baskerville, the printer of Birmingham, invented the wove covering. The edition of Virgil which he printed in 1757 was the first book in which wove paper was used.

compact. This wove covering is made in different weaves, such as basket weave and the like. The average number of wires in the ordinary weave is about 52 to the inch. This covering is applied to the wooden frame of the mold over a backing of coarser woven wire, and is stretched so as to lie flat. It is then tacked and bound with the strip of copper in the same manner as the laid covering. The wove covering is also sewed to the wooden ribs, but the stitches are farther apart than in the laid covering, averaging two stitches to the inch. Along the four edges of a wove mold, the wire gauze is pierced with holes, to help drainage; these holes are about three-eighths inch apart, and come just under the edge of the deckle, when it is placed on the mold.

4. The Deckle.—Over the mold, whether a laid mold or a wove mold, is fitted the deckle,[1] which is shown on a mold in Fig. 3 (*a*). It is this deckle that determines the size of the sheet to be made on the mold. For every size of paper, there must be two molds and one deckle; and the deckle must fit each mold equally well, and must slip on and off easily. A sectional view of the deckle, taken on the line *ab*, is shown in Fig. 2 (*a*). Fig. 2 (*b*) shows a corner of the deckle, as viewed from underneath, that is, when looking at the side that lies next to the mold.

The making of the molds and deckles is extremely particular work; it requires not only great skill but also a good knowledge of materials. The wood used must be seasoned with care, as it has to stand the strain of being in and out of warm water continually. There are no firms making molds for handmade paper in America, and but four in England, which supply most of the English and continental mills. Most vat mills employ an experienced mold maker and wire worker.

FELTS AND VATS

THE FELTS

5. Characteristics of Felts.—The **felts** are used to **couch, or lay,** the sheets of paper on, when they come from the mold. For each sheet of paper, there must be a felt, the paper being interleaved by these woolen cloths. The felts must be several inches longer each way than the sheets of paper being made; and for every

[1] From the German "deckel" or the Dutch "dekfel," meaning cover.

color of paper, there must be a separate lot of felts. The domestic felting of the kind used on the paper machine will not do for making handmade sheets. The felt for use in a vat mill must be specially made for the purpose, the English product being the best. Woven felts for handmade paper are described by Desmarest[1] in his late eighteenth century work as follows:

"The felts have two surfaces, finished with different naps. That side which has the longer nap is applied to the couched[2] sheets, and on the side with the shorter nap, the fresh sheets are laid. If this arrangement of felts were changed and the sheets were laid on the surface with the long nap, not only would they not apply themselves with ease, but the long hairs would injure the texture of the paper. It is also better for the layman, when he comes to take the sheets from the felts, that they are couched on the short-hair side, as they are then lifted off more easily. The felts should be firm enough to spread evenly upon the sheets of paper without wrinkling, and should be supple enough to enable the sheets of paper to be couched without difficulty. As the felts have to resist constant wear from handling and are subjected to great pressure in the press, they should have a strong warp, composed of combed and well-twisted wool.

"The felts should quickly absorb and give up again a certain amount of water; their weft should be of carded wool, loosely spun, and woven in the same manner as light cloths. In this way, the texture of the felt is not marked upon the paper, thereby injuring the grain by the irregular impressions of an uncovered warp and weft. If the stuff were too closely woven, like ordinary cloths, or even the finest kinds, it would not absorb enough water to enable the sheets to adhere when couched upon it. The general principle is that the wool of the felts should correspond in fineness with the finer grain and more homogeneous texture desired in the paper."

For fine watermarking and banknote papers, fine flannels are used with good results. The felts are most important; and the proper character of felt to use depends on the kind of paper being made. Writing, drawing, and printing papers require different

[1] Desmarest, N.: Art de fabriquer le papier. (Art of papermaking.) Des arts et métiers mécaniques de l'encyclopédie méthodique. (From arts and mechanical trades of the methods encyclopedia.) Vol. 5, pp. 463–595 Paris, 1788.

[2] *Couching* a sheet means transferring it from the mold to the felt.

feltings. A fine watermark may be almost completely obliterated by the use of a coarse or lightly woven felt. It is always possible to detect the felt marks in a finished sheet of paper, except in the case of a light-and-shade watermark, where the felt used was extremely fine in texture.

6. Difference between Felts for Machine-Made and Handmade Paper.—The difference between the felts used on machine-made and those made for handmade mills is given in the following account, which was kindly furnished the writer by Mr. Bertram Porritt, an English authority on the weaving of wool: "Felts for machine-made papers are made endless, are of a much opener texture, also lighter in weight, and are constructed so as to pass the water more quickly than those prepared for handmade papers. The reason for this is that in the case of felts made for machine-made papers, the felt is continually running, and its speed corresponds to that of the machine, which varies, and may reach a maximum of 1400 feet per minute. The wet felt, therefore, has only a very limited time for the water to pass through it, which is pressed out by the press rolls. Felting for handmade papers is a much thicker material; it differs in construction, and is manufactured in piece form, usually about 60 yards long and 60 inches wide, which is then cut to suit the size of the sheets to be made. The great difference between hand felting and felting made for the machine is that hand felting acts as a couch in addition to acting as a wet felt, and it therefore follows that it must be of a close and very even texture.

"Wool has to be specially selected for making hand felting; it must be uniform in staple and of a non-shrinkable and springy character. The felting is composed of all pure wool, and no vegetable fiber is used. The yarns have to be spun evenly and round, otherwise, they would not stand the strain of weaving, which is one of the most important details of manufacture, since this process (weaving) forms the foundation of the felting. If the weaving is not firm and well constructed, the felt soon becomes thin and poor.

"There are various styles and designs of weaving, but the particular form selected is generally determined by the paper-maker, in accordance with the particular grain or finish of paper required. In many instances, the grain in the felt is made to

give a diagonal appearance to the paper. There are other grains, such as the oatmeal and basket patterns; but these vary in prominence, in accordance with the wish of the paper manufacturer.

"Following the weaving, the next process is the finishing, which consists of scouring, milling, raising, and brushing. Great care must be exercised in the scouring process to make certain that no strong scouring material is used, since that would injure the fiber of the felting. All loose hairs or fibers must be cleared from the felts; otherwise they will get on the paper and cause the paper-maker no end of trouble."

THE VAT

7. Construction of the Vat.—Fig. 5 shows the interior of a vat house where handmade papers are made. The **vat** *d* is the receptacle that holds the pulp from which the sheets are formed.

FIG. 5.

The vat may be of stone, copper, or wood that is lined with metal; it is about 5 feet square at the top and 4 feet deep, the front and back walls slanting toward the bottom, as shown. When made of stone, the walls are about 3 inches thick, and the joints are mortised and leaded; if made of metal, the corners are bolted. Nearly all the old vats are round, and this type is still used in some mills on the Continent. The round vats are usually made of wood and constructed like a wooden tub, with staves and

hoops; they are then lined with sheet lead or copper, and are soldered at the joints. Extending the full length of the vat, at the bottom, is a paddle wheel, which is called a **hog**; it is used to keep the pulp in motion, so the fibers will not fall to the bottom of the vat and leave only water at the top.[1] The hog must be run at low speed.

8. Purpose and Use of Vats.—Each vat in a mill is supplied with its own stuff chest *o*, Fig. 5, which is also kept agitated, to keep the pulp from settling. The vat and the stuff chest are connected by a pipe and an arrangement known as the **mixing box,** *h*, which supplies the pulp to the vat by means of a pump. The pump can be operated so that much or little pulp will enter

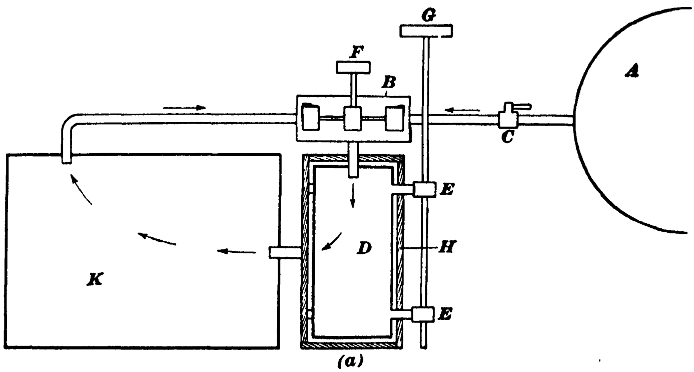

Fig. 6.

the vat, according to the weight and size of the paper being made. The stuff chests should be located above the vats, and the beaters should be placed on the floor above the vats and stuff chests.

The arrangement of equipment for handling paper stock is shown in greater detail in Fig. 6. The stock flows by gravity from the stuff chest *A* through valve *C*, which regulates the rate of flow, to a bucket pump *B*, known as the **mixing or lifting box.** This series of six buckets lifts the stock so it will run into a brass knotter *D*, which is kept in constant motion by being joggled

[1] In ancient papermaking, when the round vats were used, the pulp was kept agitated by means of a pole, fitted at one end with a wooden disk pierced with holes, somewhat like a sieve. This stick was used at intervals by the vatman to keep the pulp well mixed.

through the action of cams *E* on a shaft; this eliminates all knots and foreign substances from the stock. From the knotter, the liquid material flows into the wooden knotter box *H*, and thence to the vat *K*; it is kept in constant circulation through the lifting box and knotter while the molds are being dipped into the vat for forming the paper sheets. Pulleys *F* and *G* drive pump and camshaft, respectively. The vatman and coucher stand as shown in Fig. 5.

The pulp is kept warm in the vat by means of a steam pipe or hot-water coil. While the paper is being made, the temperature of the pulp should be kept at from 80° to 95°F.; it should never be allowed to get above 110°F.

At the side of the vat, close to the top, is a box that is kept filled with water, in which the vatman can wash his mold, in case a sheet becomes rubbed, which makes it necessary to wash off the fibers before proceeding with another sheet. Across the top of the vat, toward the back, is a platform *g*, Fig. 5, called the **bridge,** the left end of which is wider than the rest of the bridge. At the back of this enlarged part of the bridge, is a piece of wood *e*, placed on a slant, which is called the **horn** or **drainage stay,**[1] against which the molds are laid for drainage. The other necessary appliances directly connected with the work of the vat are the **couching tray** *i*, which slides out on the **truck** *l*, when a post has been made and is to be taken to the **press** *m* for pressing. The **lay stool** (felt board) *k* holds the sheets of paper that are taken from between the felts after pressing, the felts being thrown up onto the felt board for further use by the coucher. The lay stool is removed when necessary to allow the couching tray to roll out on the track.

FORMING THE SHEETS

9. Three Workers Required.—In making paper from the vat, three workers are required for each vat. The most skilled of these is the **vatman** *a*, Fig. 5, whose duty is to form the sheets. Next in importance is the **coucher** *b*, who takes the sheets from the mold and couches, or lays, them on the felts. The third workman is the **layman** *n*, who separates the sheets from the felts, after pressing, lays the paper in a neat pile, and returns

[1] In England this notched stay is known as the *ass*.

the felts to the coucher for further work. Each step in the process will now be described in the order in which it is performed.

10. Making the Sheet.—The vatman stands on a platform in front of the vat and grasps the mold, one hand on either side at a convenient point of balance: with the deckle in position, his thumbs extend along the top of the deckle and his fingers are under the mold. He must grasp the mold firmly, but not in a tense manner, since a great deal depends on the freedom of the muscles under his control. The vatman now holds the mold nearly at arm's length over the vat in an almost vertical position, and, with a quick but steady 'scooping' movement, he plunges it into the vat, bringing it out again covered with pulp into a horizontal position close to his body, a few inches above the surface of the vat. By an almost imperceptible tilt forward, he causes a wave of pulp to flow across the surface of the mold from back to front, and this has the effect of leveling the pulp. As this wave flows across the mold, a few rapid side shakes are imparted to it, which cause some of the fibers to set in a cross direction, and as the wave reaches the far side, the mold is shaken several times somewhat vigorously, first toward the vatman and then away from him, until the bulk of the water in the pulp has passed through the wire gauze forming the face of the mold and the fibers appear set in the form of an even sheet on top of it. This manipulation of the mold is known as the **vatman's stroke.** In the course of practice the vatmen become so dexterous that the formation of a sheet from the time the mold is dipped to the time the final shake is given occupies only a few seconds. Some vatmen pick up on the mold only sufficient pulp to make a sheet of the requisite weight; others pick up more than is sufficient and throw off the excess at the end of the stroke, just before the fibers become 'set.' The thickness of a sheet depends primarily on three things: first, the depth of the deckle; second, the consistency of the pulp; third, the experience of the vatman in knowing just how much pulp to pick up on his mold.

Except in the case of very small molds, great care is taken not to submerge the mold completely when making the sheet; if the whole mold is submerged, great difficulty is experienced in pulling it out again, owing to the suction. This would not only make the work extremely laborious but would also interfere with the

vatman's stroke, and would ruin all chances of making a good-looking sheet. To avoid this suction being set up, only about three-fourths of the mold is actually submerged.

11. Removing the Deckle.—The mold, with the wet sheet, is then laid in a perfectly level position on the corner of the vat at the vatman's left, where it remains until sufficiently hard to permit removing the deckle. The degree of hardness desired is determined by the peculiar look that gradually comes over the sheet, which dries from the edges to the center of the surface, as the water drains from underneath and evaporates from the top. The vatman then takes off the deckle and passes the mold holding the semi-wet sheet to the coucher, who leans the mold against the stay (horn) at the proper angle, and leaves it there until it is drained enough to couch, or lay, on the felt.

12. Making the Post.—In the meantime, another mold has been pushed along the bridge by the coucher to the vatman, who now places the deckle on it and proceeds as before to make another sheet. When the mold just used, which leans against the stay with the semi-wet sheet on it, has had a few moments for draining, the coucher grasps the upper edge of it with his left hand and swings it across in front of him, seizing the other side with his right hand, at the same time releasing it with his left. The mold is now held in a vertical position, with the lower edge on the right edge of the post of felts; it is then turned over so that the semi-wet sheet comes into contact with the felt. By giving the requisite amount of pressure on the back of the mold during this turning-over movement, the sheet of paper adheres to the felt and detaches itself completely from the face of the mold: this is known as the *couching of the sheet.* The mold is now turned up again into a vertical position on the left side of the post, and from thence it is raised and pushed along the bridge until it comes to rest in front of the vatman. The coucher's next duty is to 'pitch' a felt on top of the sheet he has just couched, and this requires a high degree of skill and accuracy. Catching up a felt from the **felt board** on his right side, he grasps one of the short ends with both hands; holding it up in front of him well clear of the post, with an outward swinging movement he drops it accurately on the wet sheet, without any dragging or wrinkling; otherwise, the sheet will be injured and

spoiled. He then proceeds to couch another sheet on the top of the preceding one, and by this means the **post** is built up to a height of approximately 18 inches. In the case of the larger sizes, a boy *c*, Fig. 5, is told off to assist the coucher in the handling of the mold and the pitching of the felts. It is advisable to lay three or four felts on the couching tray to receive the first sheet of paper laid down, since it is difficult to couch a sheet on a felt laid directly over a hard surface.

The two workmen (vatman and coucher) must regulate their movements so that they work in perfect unison, which is far more difficult than might be supposed. The rapidity of the work depends upon the size of the molds, the thickness of the sheets being made, and the grade of pulp.

The coucher and vatman must shake their hands each time they begin a new sheet, as the slightest drop of water on the top of a newly molded sheet will cause a large transparent spot in the finished sheet.

13. Pressing the Post.—The couching tray, holding the completed post, is rolled on a track to the press, where the pile is subjected to a pressure varying from 100 to 150 tons, which expels a very large proportion of the water. Before opening the press, it is well to scrape off the excess water from the edges of the felts with a wooden paddle, since, when the press is opened, this water would run back into the paper.

When the post is removed from the press, the third workman, called the layer or layman, separates the sheets of paper from the felts. This he does by taking each sheet by the two corners nearest to him and lifting the sheet so that it pulls away from the felt evenly and without strain. He places the sheets of paper in a pile, taking care that the four corners of each sheet fall directly over the corresponding corners of the sheet underneath. The felts are placed on the **felt board,** ready for the coucher to use in making the next post. After they have been made into a neat pile, the sheets are pressed slightly and allowed to remain in the press over night. The next day, they are separated, built up again in a different order, and pressed again; this is called **exchanging,** or **parting,** and may be repeated until the required finish that can be obtained by this means is developed. The sheets are then ready to be taken to the drying loft.

The three workmen can make from two to twelve reams of paper a day, the amount depending upon the size of the sheets and the kind of paper being made.

The vats should be drained and thoroughly washed at least once a week; the felts should be washed every fortnight in warm water to which a small quantity of ammonia has been added, or with wool soap. The molds should always be well rinsed after each day's work, as the pulp, when dry, clings to the wires tenaciously.

14. Skill Required of the Vatman.—To be able to make each sheet of a ream of paper weigh the same and be of uniform thickness throughout its entire extent makes it imperative that the vatman possess a great amount of skill and practice. The larger the mold the harder it is to form a perfect sheet; consequently, it is well for the beginner to start with small molds, gradually increasing the size until the larger ones are reached. It is not possible to make really even sheets without at least 5 years of constant application at the vat; even then, the 'stroke' may be lost, and the worker may become unable again to make any kind of handmade paper. The work at the vat requires patience, endurance, strength, and a keen sense of weight; and since the vatman's hands and arms are constantly in and out of warm water, the work is anything but agreeable. Unless one has a wholehearted desire to make handmade paper, he should never attempt it.

DRYING, SIZING, AND FINISHING

15. Drying the Paper.—The **drying loft** of a mill making handmade papers should be arranged so as to get a circulation of air from all sides by means of shutters for summer drying; for winter and rainy weather, the loft should be heated, the temperature ranging from 75° to 80°F. It is best to dry the paper slowly. When the paper comes from the press, after the last exchanging, or parting, the sheets form more or less of a solid mass. The paper is taken off in spurs of four or five sheets, no attempt being made to separate them, and these spurs are hung separately over hair ropes $\frac{3}{4}$ inch in thickness, or over half-round sticks made of whitewood. These ropes or half-round sticks are arranged so as to fill the loft completely, using all the space available. The

spurs are hung up by use of a cross bar and handle resembling a letter T, and frequently called a **cross.**

The length of time required to dry paper depends upon the temperature of the loft, the size and thickness of the sheets, the amount of exchanging, or parting, and the width of the supports on which the paper is hung to dry. All paper should be left in the drying loft until thoroughly dry, dryness being determined by the rustle of the sheets. When the spurs are taken down, the sheets are still somewhat stuck together, and they must be separated, or *stripped*, as it is called, before the next process is undertaken—which is sizing.

16. Sizing.—Animal size is generally used for handmade papers; it can be made direct from the hide cuttings, or it may be purchased in the regular commercial form. In the latter case, which is the most satisfactory, the cakes of size are soaked in cold water, and the temperature is raised until about 95°F. is reached. Owing to the high cost of the regular commercial glue cakes, many papermakers prepare their size direct from hides, bones, etc. Paper made from hard rags, slightly boiled, will require a thin size at a high temperature; but for paper made from old, soft rags, a thick size at a lower temperature will be found better practice. Further information on methods of preparing size is given in the Section on *Sizing*, Vol. IV.

The older practice was to put the liquid size in a copper tank of suitable dimensions, and keep it hot by means of a steam pipe or hot-water coil. The workman then took a pile of sheets of paper, from 100 to 150 sheets; holding one end of the pile in his left hand, he used the other hand to spread out the sheets and immersed the lot in the hot size, taking care to have all surfaces of the paper come into contact with the liquid. After a pile about a foot high had been sized, the sheets were placed in a press and slightly compressed. The lower plate of the press has a metal drain around it, to catch the size that is forced out of the sheets, which may be saved and used again.

17. A Modern Method.—A more modern method for sizing handmade sheets is based on the size press of a paper machine. Fig. 7 shows the essential features of the apparatus. The dimensions given below may vary, according to conditions. The size tub *T* is about 12 inches deep, 12 to 30 feet long, and as wide as

is required to handle the largest sheet to be sized; usually a width of 60 inches is satisfactory. It is to be noted that the longer the tub the faster it can be operated. Pitch pine, 3 inches thick, may be used to make the tub. An inlet *I* and an outlet *O* are provided, the bottom of the tub sloping slightly toward the outlet *O*. A copper or brass steam coil *C*, placed in the bottom of the tub, runs the full length of the tub; it controls the temperature of the sizing solution. A lower felt F_1 and an upper felt F_2, both endless, are carried by fixed rolls R_1 and R_2, guide rolls G_1 and G_2, and stretch rolls S_1 and S_2, respectively, and are held in the size bath by rolls *R*, which are 4 inches in diameter and are spaced 2 feet apart. P_1 and P_2 are wood or bronze press rolls, between

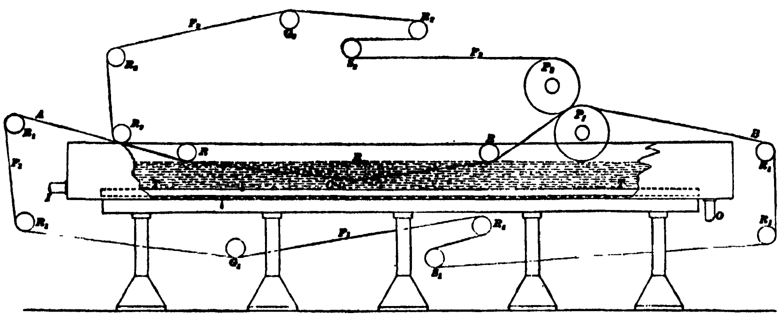

FIG. 7.

which both felts pass. Other arrangements for guiding and stretching the felts may be used.

The operation of this apparatus is as follows: The size solution, which is usually gelatine of about 5° Be. (sp. gr., 1.0357), is prepared, and is introduced into the tank until the felts are well covered. The temperature is adjusted by regulating the supply of steam to the coil *C*. Hot size penetrates more rapidly than colder size. The sheets of paper are laid on the lower felt at *A* and carried to the size bath; they are kept in position by the upper felt. The two felts, with the paper between them, pass between the press rolls P_1 and P_2, and the excess of size is squeezed out. If desired, an extra pressure can be put on the press rolls by means of levers and weights. Special felts that have an open weave are used, and extra holes are sometimes punched in them, to assist the escape of air and froth and excess size. The upper felt should have a longer nap than the lower felt, so that the sheets

will pass on to where the attendants, usually women, pick them off and pile them on a truck, to be taken to the drying loft.

18. Finishing.—After sizing, the paper has to be dried and **finished** by a method similar to that used for the best grades of machine-made papers. This is a process of pressing the sheets between zinc plates or boards that have a highly finished surface. After plating (finishing), the paper is put in piles, separated every 6 inches or so with heavy walnut boards, and left in the press several days, to give added finish.

The nature of the finish given to the paper naturally depends upon the purpose for which the paper is to be used. Those papers used for water-color painting, and some drawing papers, are only slightly pressed; but for writing, etching, engraving, and letter-press printing, the papers are generally given a high degree of finish. The varieties of finish and texture that can be imparted to handmade paper are practically limitless.

19. There is considerable loss in making paper by hand, owing to tears in the sheets, knots, water drops, hairs from the felts imbedded in the paper, drops of size, bubbles, holes, blurred watermarks, ruffled laid lines, and pieces of rust from some part of the vat, but particularly the steam pipe. It is not unusual to discard fully 20% of the product as imperfect. The best of the discarded sheets are sold as *seconds*, or *retree*, and the remainder is re-pulped and made into paper for wrapping the perfect reams.

WATERMARKING HANDMADE PAPERS

20. Simple Watermarks.—The **watermark** in paper is caused by wires of different gauges, made in the form of letters, monograms, or designs, and fastened to the wire covering of the molds. In a laid sheet of paper, the laid and chain lines may be seen when the sheet is held to the light, and any wire work that is added to the top of these wires may also be seen. As it lies on the mold, the top surface of the wet pulp is flat, but the bottom surface is thinner where it touches the wires of the watermark. This slight difference in thickness is what gives transparency to the watermark.

The simplest form of watermark is made with thin wires that have been twisted to the form of the letters or design, as shown in

(*b*), Fig. 3. These wires are of brass, silver plated, and many different gauges of wire are used for as many different kinds of

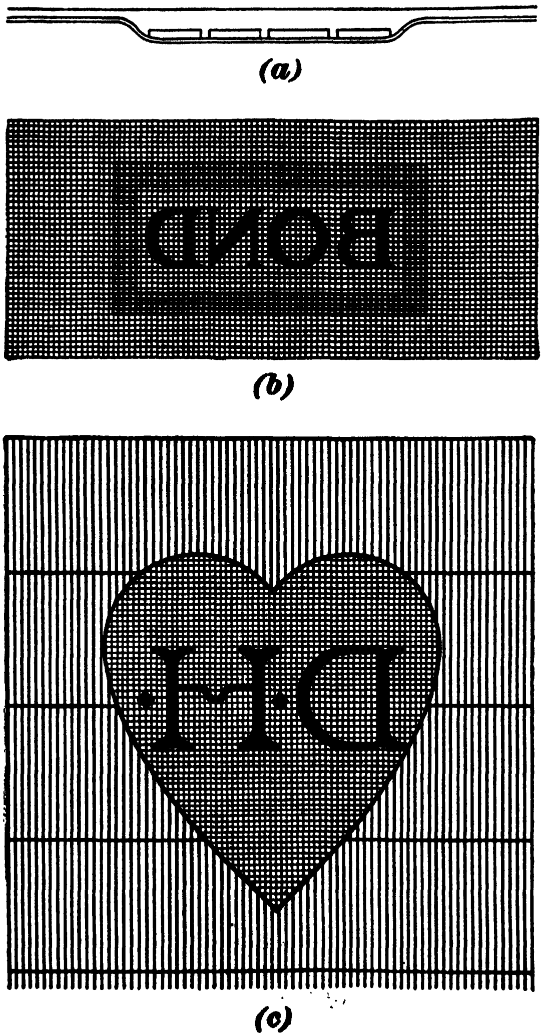

FIG. 8.

paper.[1] Letters and designs may also be cut from sheet silver

[1] In most watermarking, the wire is twisted into the required designs without fastening at the joints; but in finer work, the joints are usually

or brass, as illustrated in Fig. 4, in which case, they are usually soldered to the wires of the mold. In the mark of the heart, Fig. 1, the letters are sewed to a piece of brass gauze or woven wire, which gives, in this case, three degrees of density, as shown more clearly in (*c*), Fig. 8.

21. These simple marks are the ones employed in the commercial handmade papers and are quite common. More complex lettering and designs may be made by the molding process, but it requires more time and ingenuity. This form of marking is used chiefly on wove molds. The letters or design are cut in a sheet of wax composition to the desired depth, two dies are made from the impression, and the wire gauze is pressed between the two dies. By this method, the letters or design may be either 'sunk' or 'raised.' The sunk mark makes that part of the sheet where the lettering or design appears heavier than the remainder of the surface, while the raised mark causes the pulp to lie thinner on the mold at that point and makes the watermark more transparent than the remainder of the sheet. Sunk impressions may also be made in a wove mold, by the modeling process, and wire or cut letters or designs may be sewed in this depression, as in (*b*), Fig. 8. A section of the same mark is shown in (*a*), Fig. 8, with the wet pulp lying over the form in three different thicknesses.

22. Colored Watermarks.—Colored watermarking is another device that has been developed in recent years.[1] For this purpose stencils made of wire cloth are employed, with the lettering or design cut in the cloth. In this work, the colored lettering or design appears inside a white sheet, and it can be seen only when the sheet is held to the light. As many vats are required as there are colors. First, a thin white sheet is couched, and on top of it is laid the colored pulp of the letters or design couched from the stencil; over the whole, another white sheet is couched, care being taken that all corners fall directly over one another. This method of watermarking is used for crests, trade-marks, and any

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hard soldered. When many designs of the same subject are necessary, the electrotype process is used. The letters are stitched to the molds, backward, with fine brass-plated steel wire.

[1] The art of colored watermarks was invented by Sir William Congreve, in 1818, and was patented in England, Dec. 4, 1819. Nearly all the original sheets made by the inventor, with the original account of his invention, are in the possession of the writer

design where one or more colors are desired. Pressed flowers may be imbedded in note paper by this two-sheet method.

23. Light-and-Shade Watermarks.—The most artistic, as well as the most difficult, form of watermarks for handmade papers

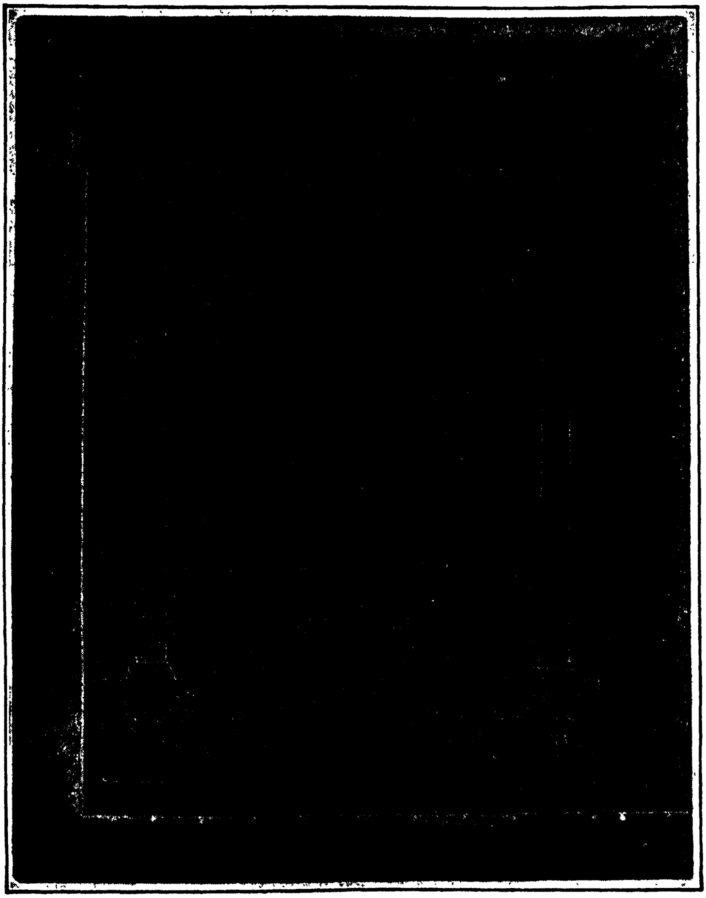


Fig. 9.

are the **light-and-shade marks,** examples of which are shown in Figs. 9, 10, and 11. These marks are made by first modeling the design in a wax composition; then dies are made from the model, and hand-woven wire cloth, which has first been annealed, is pressed between the dies, after which the wire cloth is hardened.

This covering is applied to the frame of the mold, with two or three backings of woven wire that have been cut and pressed to allow for the impressions in the top covering. The different heights of the wire gauze (cloth) hold the pulp in as many different thicknesses, and they cause the light-and-shade watermark, which may be seen when the paper is held to the light.

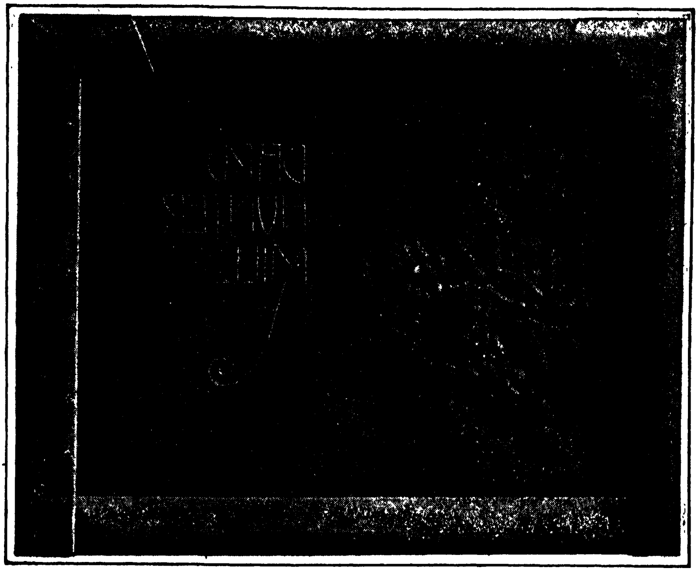


FIG. 10.

In Fig. 9 may be seen a mold made by the writer.[1] Note that the oval center makes a light-and-shade mark of a different color from the rest of the figure. This effect is accomplished by the use of stencils. The oval and outside lettering are blocked out in turn, one overlapping the other $\frac{1}{8}$ inch, which unites and binds the two sections of the sheet. In couching a sheet of this nature, great care must be exercised to get the mold to lie on the felt at exactly the same place and in exactly the same position in

[1] This mark shows, in the oval, William Rittenhouse, the first papermaker in America, at work at the vat. His watermark, used when the mill was established, or shortly after, appears under the name Bradford, the first printer in America to use this paper. The Rittenhouse Mill was founded in 1690. On the other side of the mold, the mark of John Tate may be seen, who was England's first papermaker, and Wynkyn de Worde was the first printer to use this paper, in 1495.

Fig. 11.

Fig. 12.

both couchings. When making sheets or partial sheets in color by the handmade process, one side of the sheet will be lighter in tone than the other, on account of the high specific gravity of the coloring matter.

Fig. 10 shows a waterwheel and a part of a mill, and Fig. 11 shows a portrait. It is to be noted that in these two illustrations, owing to a mistake of the photographer, the deckles have been wrongly placed on the molds. The brass-bound corners should

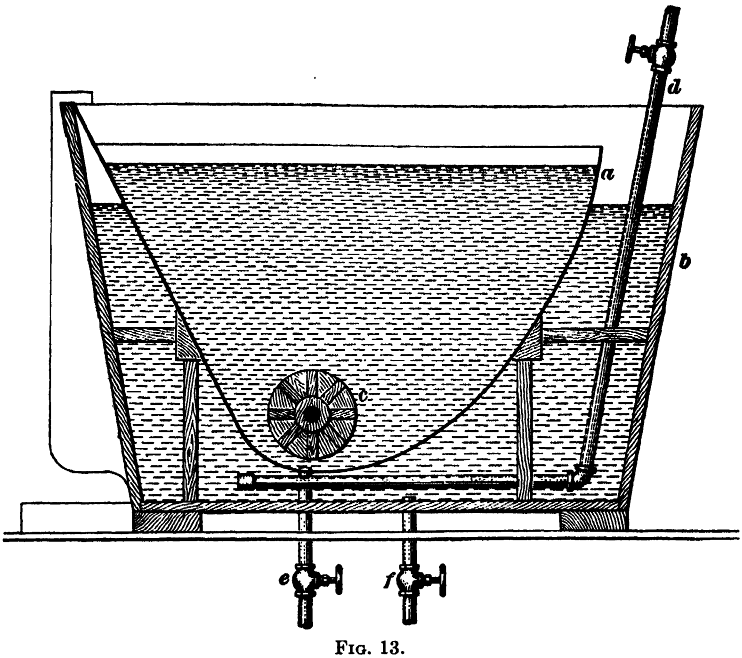


FIG. 13.

be at the bottom of the mold, or the side toward the vatman. The deckles are made to fit the mold properly only when placed in this way. Fig. 12 shows a photograph of a sheet made from the mold shown in Fig. 11.

24. Special Vats.—All elaborately watermarked papers must be made from a special vat, because if made in an ordinary vat they would show specks of rust and dirt from the steam pipe, etc. A sectional view of a bank-note vat, as it is called, is shown in Fig. 13. Here *a* is a copper tank, placed within a larger wooden

tank *b*. The water between the two is heated by a steam pipe *d*, which, in turn, heats the pulp in vat *a*, from which the sheets are dipped. Vat *a* is fitted with a hog *c*, which keeps the pulp from settling. The outlets for each vat are shown at *e* and *f*.

For making pulp for these fine watermarked papers, a tile-lined beater of small capacity is used, which is fitted with brass bed-plate and beater knives.

USES AND QUALITIES OF HANDMADE PAPER

25. Uses of Handmade Paper.—Handmade paper will always have a legitimate use and will probably always be made for special purposes, no matter how closely the machine may imitate it. In England, the making of vat papers is quite a large industry, there being at the present time fifty-five vats in operation. Handmade sheets are used in the United States for fine book printing, etchings, engravings, woodcuts, stationery, and advertising announcements. In England, and on the Continent, where the art is better developed and understood, there is a larger field for these papers, since they are used not only for the purposes mentioned above but also by the legal profession for wills, deeds, and documents of all kinds, and by the government for bank notes and records and for account books.

26. Quality of Handmade Paper.—For some purposes, handmade papers are superior to those made on the paper machine, even when the machine is furnished with the same grade of pulp. This is due to the *four-way shake* that the handmade paper receives, as compared with the two-way shake given to the machine-made paper. This four-way shake has a tendency to unite and cross the fibers, thus rendering the paper stronger and making it more durable. The handmade paper also has an advantage over the machine-made paper in the matter of natural shrinkage; a sheet of the former will shrink about $\frac{1}{2}$ inch to the foot; and even more, if composed of a large proportion of linen fibers; furthermore, the shrinkage is uniform in all directions. It is also impossible to get the quality of texture and artistic feeling in machine-made paper that is characteristic of the handmade product.

Another important feature in favor of handmade paper is the excellence of the watermarking, an effect that cannot even be

approached in the machine-made product. This is due to the fact that in handmade papers, the pulp lies over the design of the watermark during the entire time of making the sheet, while in machine-made paper, the watermark is simply pressed into the wet pulp *after* the sheet has been formed.

27. Deckle-Edge Paper.—In Fig. 14, there are shown eight examples of deckle edges on paper. An old piece of paper of American make, from 1730, is shown at (*a*). In this case, the

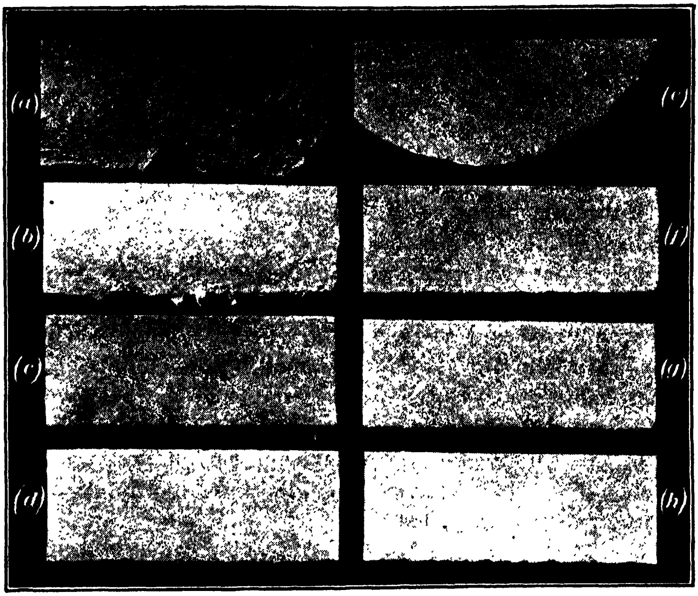


FIG. 14.

wooden deckle was badly fitted to the mold, and the wet pulp ran under the edges, which caused the extreme deckle edge. The line drawn on the specimen shows where the edge of the sheet ought to have stopped, had the deckle cut the pulp properly. At (*b*) is shown a ragged edge, but one made on a well-fitted mold and deckle, the extreme deckle edge being caused by excessively long fibers, which spread out when the sheet was couched. A laid sheet is shown at (*c*), and the deckle edge is made by a tearing wire, a square wire sewed to the mold, which makes an impression, so that the sheet when dry can be easily torn along the line made by the wire; this makes a rough edge that somewhat

resembles a genuine deckle. This method is used in making small sheets of note paper or cards, as it enables the workman to make from 4 to 8 sheets of note paper on a mold at one time. In this method, every sheet has from two to three false deckle edges. A wove deckle is shown at (*d*), and a round, or filter deckle, at (*e*). Specimen (*f*) is a laid paper with a deckle edge of good appearance and technique. A cylinder-mold sheet, or imitation handmade, is shown at (*g*); these imitation sheets have four deckle edges, as in the genuine handmade, only the edge is of a different character, and the difference is much too subtle a thing to describe. An ordinary machine-made deckle is shown at (*h*); this edge is due to cutting the web in strips with a jet of water on the Fourdrinier wire. Such a sheet can have but two deckle edges, which are opposite.

28. European Handmade Papers.—The handmade papers made in Europe differ greatly in the various countries. The English is by far the best, as their material is usually of the highest quality, and their workmen seem to possess the greatest skill in making even and well-balanced sheets. The French and Dutch handmade papers are fairly good, the French being light and supple, while the Dutch display a tendency toward heaviness. The Italians made good vat papers at one time; but since so much of their produce has been exported to America, they have cheapened their raw material, and now their handmade papers are inferior as formerly.

IMITATION HANDMADE PAPER

29. The Cylinder-Mold Deckle.—In recent years, machines have been constructed for the purpose of imitating genuine handmade, or vat, papers. These special machines are known as **cylinder-mold,** or **cylinder and vat, machines;** and they are so made that the sheets formed on them may have four deckle edges. Heretofore, the four-deckle sheet has been possible only by forming it on the hand mold, as previously described. The deckle edges made on one of these cylinder machines differ materially from those produced on a hand mold, but the difference is not easy to describe. The cylinder-made deckle is more even in appearance than the edge of a genuine handmade sheet,

the former having that machine-made quality that always separates the mechanically made thing from that fashioned by the human hand. A machine can be made to imitate hand work

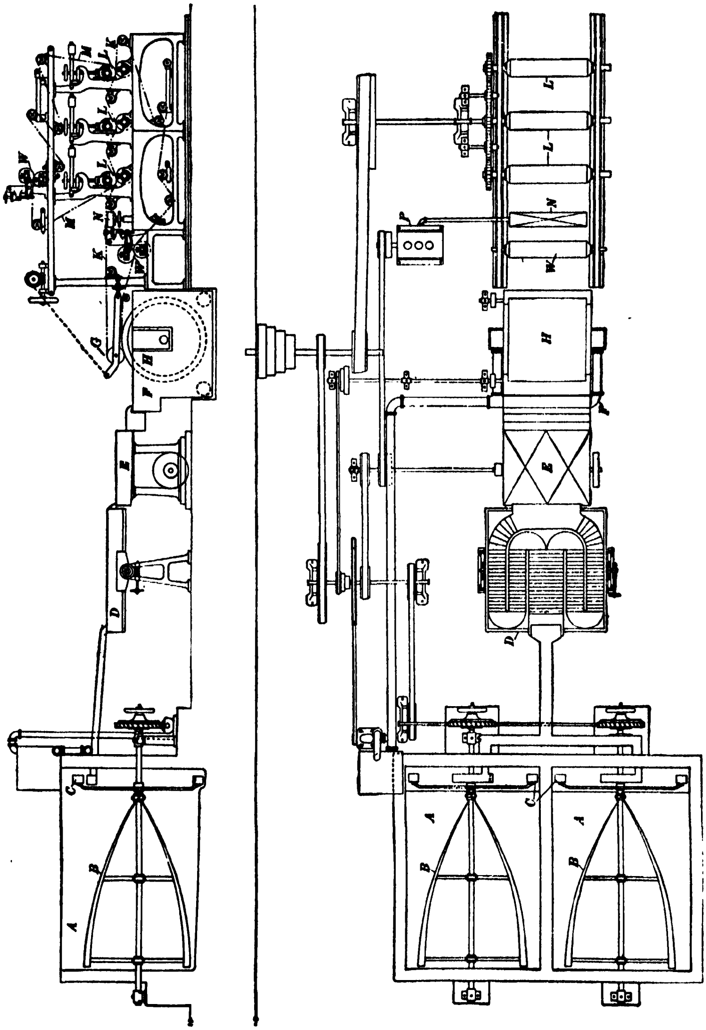


Fig. 15.

up to a certain point, and then the product is obviously machine made. Power looms have been constructed to imitate ancient Chinese and Persian rugs; but the genuine rugs always carry

with them that indefinable technique that a machine can never duplicate.

30. Cylinder-Mold Paper Machine.—The cylinder-mold paper machine is shown in full in Fig. 15. It consists of two horizontal stuff chests *A*, *A*, fitted with agitators *B* and lifter wheels *C*, from the buckets of which the pulp, after being diluted, flows over a sand table *D*, through a flat strainer *E*, to the vat *F*, in which the cylinder mold *H* revolves. The vat is made of heavy sheet copper, and the cylinder is of brass; all the piping used in the machine is also made of a non-rusting material. The couch felt *K* passes between three presses *L*, *L*, *L*, and the paper is carried between felt *K* and an upper felt *M*; hence, a felt is on both sides of the sheet. Both felts are fitted with washers *W*, and a suction box *N* helps to dewater the paper; *P* is a suction pump. The presses consist of a bronze top roll and a rubber-covered bottom roll, driven by machine-cut gears; thus, they both start and stop simultaneously, and there is no slip between them. After passing through the presses, the paper is led over four drying cylinders, placed in one row and furnished with one felt. This makes the paper smooth on one side only; but this one-sidedness disappears later, since the paper is usually sized or otherwise treated afterward. The paper forms by the deposit of fibers on the surface of the wire-covered cylinder *H*, the white (or waste) water passing through and being conserved for diluting the stock. The felt *K*, pressed against the cylinder by the couch roll, picks up the paper and carries it between the press rolls *L*.

When the paper is not taken off in single sheets (as described later), it runs onto a reeling apparatus for further treatment. In this form, the machine is adapted to the manufacture of endless paper or webs; and as the cylinder rotates in the stock, currents are set up that tend to lay the fibers in the direction of rotation. This causes the paper to be much stronger in the running direction than in the cross direction. This characteristic is just what one tries to avoid in the imitation of handmade papers; and it can be partially overcome by using agitators, which maintain even distribution of fibers, and also by running the machine slowly. The slower the cylinder revolves the smaller will be the difference in strength and stretchability of the paper in the two directions. For this reason, the production of the machine is

limited. The machine can be run at very slow speeds up to 40 feet per minute.

31. The Cylinder Mold.—The cylinder mold, Fig. 16, is an ordinary cylinder composed of brass ribs, which support a coarse, laid covering, also of brass. This covering acts as a support to

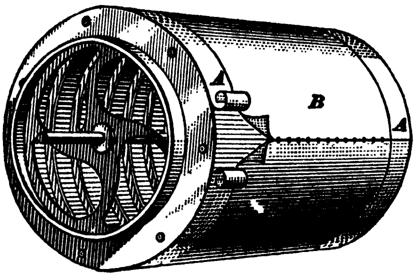


FIG. 16.

the removable outside covering *B* on which the wire watermarks are fastened. The watermarks made in the paper on one of these machines are clear and distinct; they are much superior to the marks made by the action of a dandy roll on a regular paper machine. However, they are not equal in many respects to the watermarks in handmade papers.

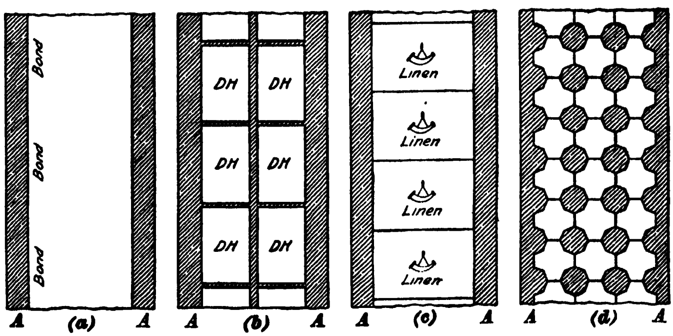


FIG. 17.

32. The Cylinder Covering.—The covering for the cylinder for forming a continuous sheet or web of paper is shown at (*a*), Fig. 17. All the parts marked *A* (shown also at *A*, Fig. 16) are waterproof cloths; they determine the width of the sheet and cause the deckle edge on the paper. At (*b*), Fig. 17, the covering

is shown arranged with the waterproof or waxed cloth so as to form separate sheets, each sheet having a deckle edge on all four sides. It is understood, of course, that the pulp will not form on the waterproof cloth. At (*c*), Fig. 17, the sheets are separated by means of a thread of cotton tissue, extending from one waxed or waterproof cloth on one side of the cylinder to that on the other side. With this arrangement, the paper is torn into sheets, along the lines left by the cotton thread, after the paper has passed through the drying battery. View (*d*), Fig. 17, shows how envelopes are made by the use of waterproof cloth, each envelope having a deckle edge on all sides. In the case illustrated at (*b*), the separate sheets must be taken, one after the other, from the wet felt; they are then piled up and subjected to pressure in a hydraulic press, and are usually dried after the fashion of genuine handmade papers.

The cylinders are made from 45 to 60, or more, inches wide, the 60-inch width being a practical size.

33. Sizing the Product.—In order to imitate genuine handmade paper as closely as is possible, the paper made on the cylinder-mold machine is not sized in the beater; it is usually tub sized in a machine similar to the one shown in Fig. 7; or, if in a continuous web, after the manner described in the Section on *Sizing of Paper*, Vol. IV.

HANDMADE PAPERS

EXAMINATION QUESTIONS

1. (*a*) What is meant by a laid mold? (*b*) a wove mold? (*c*) by antique laid? (*d*) When was wove paper first used?

2. (*a*) Name the principal characteristics of felts used for handmade papers. (*b*) Which side of the felt is laid on top of newly couched sheets, and why? (*c*) Why do felts for machine-made and handmade papers differ?

3. What should be the proper temperatures of: (*a*) the pulp in the vat? (*b*) the size? (*c*) the drying loft?

4. (*a*) Describe the vat. (*b*) Explain how the sheet is made.

5. After the sheet is formed, (*a*) what is the next step? (*b*) How is the deckle removed?

6. Explain how the post is made and pressed.

7. (*a*) Mention some differences between handmade and machine-made paper. (*b*) Which is the stronger, and why?

8. What is meant by exchanging, or parting, and why is it done?

9. What is the difference between a watermark in handmade paper and one in machine-made paper, and which is the better, and why?

10. (*a*) What precautions are taken in the preparation of pulp for special papers? (*b*) Name some uses for handmade paper.

11. How is handmade paper dried?

12. (*a*) Describe the sizing of handmade papers. (*b*) What materials are used for sizing?

13. (*a*) Can any kind of pulp be used for making a light-and-shade watermark? (*b*) How is the pulp treated for this practice?

14. What is deckle-edge paper, and how is it made?

15. Describe the cylinder mold and covering for the machine used for making imitation handmade paper.

SECTION 3

PAPER FINISHING

By W. D. SOMMERVILLE

Revised by VINCENT WATERS

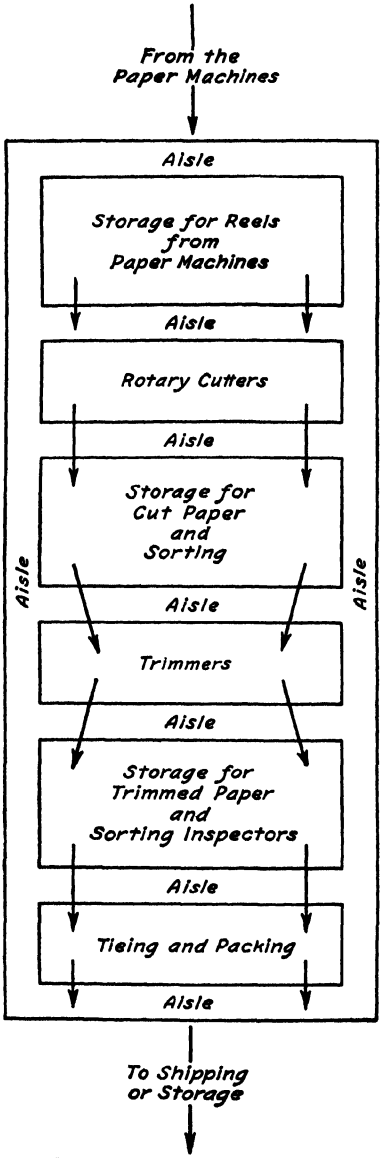
PRELIMINARY FINISHING OPERATIONS

GENERAL STATEMENT

1. Purpose of Finishing.—The finishing operations in a paper mill may be said to begin immediately after the paper leaves either the paper machine or the dry loft, depending on whether the paper is machine dried, air dried, or loft dried. In general, the finishing processes consist of: (*a*) cutting the paper into sheets or winding into rolls for shipment; (*b*) sorting (*i.e.*, removing the sheets that are not up to standard), counting, trimming, sealing, labeling, and packing. Ruling, folding, pasting, and embossing are sometimes classified as finishing operations, and also will be described. Pasting, or laminating, may be accomplished with the paper in the form of either sheets or rolls.

2. Order in Which Operations are Considered.—The finishing operations will be described in sequence. Operations common to both machine-dried and loft-dried papers will be considered first; then will follow the special operations peculiar to loft-dried papers only. Air-dried papers, as received from the drying machine, are handled in the same manner as machine-dried papers.

3. Importance of the Finishing Department.—So many fields have been opened to the manufacturer and converter of paper that many articles formerly made of other materials can also be made from pulp or paper in some form. The finishing department, because of the wide diversification of these products, is of greater importance than ever, and it requires a highly trained personnel. Many mills are appointing technically trained men for the more important supervisory positions.



Schematic Layout of Finishing Room

FIG. 1.

In order to have an efficient operating department, the workmen in it must be mobile to a certain degree. The finishing-room superintendent must train his male and female help to handle several jobs capably. The following groups of workers should be able to interchange jobs:

Group I: Rewinder operators; embosser operators; plater operators; supercalender operators.

Group II: Tyers; ream sealers; trimmer operators; layboy operators; cutter operators.

Group III: Roll wrappers; helpers on various machines.

Group IV: Counters; sorters; folders; cutter girls; inspectors; labelers.

4. Necessity for Care and Skill.—To produce a good sheet of paper, care and skill must be exercised throughout the entire operation, from the purchase of the raw materials to the shipping of the finished product. It is assumed that the paper arrives in the finishing room in good condition, in order to keep broke at a minimum. Paper with the following faults should not be sent to the finishing department if avoidable: incorrect size and weight; incorrect moisture content; poor formation and bulk; bad rolls; excess

dirt and marks on sheets caused by the paper machine; wrinkled, cockled, or curly paper. Proper control of these essentials for high production is a function of the manufacturing department.

5. Routing.—Efficiency can be kept at a maximum if each operation is definitely planned in advance: no machines should be kept waiting for material, nor should they be so oversupplied that the material hampers movement, or occupies the space that should be used for other purposes. In order to route advantageously, the time that each operation is to take must be known, so that when the product has gone through one operation it can start at once on the next succeeding operation or process. All processes should be standardized, such as speed, time required to move the material, and other obvious details of the operation. The correct working out of details will increase the efficiency of finishing, and will insure the maximum output. There are times, however, when conditions may not warrant the expense of an elaborate department; in that case, good supervision is of even greater importance.

6. Supervision.—The finishing department is usually managed by a finishing superintendent, who has complete charge of all operations. He is responsible to the plant manager, and he should keep in close touch with the sales department and the engineering department. The following is a typical finishing-room organization chart.

MANAGER

Sales Department	Finishing Department	Engineering Department
Converting Supervisor	Finishing Supervisor	Shipping Clerk
Rewinder operators	Roll wrappers	Weighman
Embosser operators	Cutter operators	Stock-room man
Plater operators	Layboy operators	Paper loaders
Supercalender operators	Trimmer operators	Truck operators
Waxing-machine operators	Room sealers	
Ruling-machine operators	Tyers	
	Girls: Counters, Sorters, Folders, Inspectors, Labelers	

7. Finishing- and Shipping-Department Layout.—The *ideal* finishing-department layout is an impossibility in most cases, because most mills manufacture several grades of paper, each of which may have a different line of travel through the finishing department. The schematic layout of a finishing room, Fig. 1, is an industrial engineer's conception of an ideal layout; and if this scheme were followed, mills could reduce their finishing costs considerably. Some mills, of course, owing to their methods and processes, might find it advantageous to change this layout in some of its details.

REWINDING AND CUTTING

THE REWINDER

8. Object.—The processes of rewinding and cutting are usually the first finishing operations to be done. The **cutters** cut the sheets into suitable sizes for further operations in the mill, or into sizes proper for shipment to purchasers, etc. The cutters may slit the paper, or this may be done on the paper machine. The slitting of paper into comparatively wide rolls was described in Section 1 of this volume.

The **rewinders,** however, are built to slit the large reel and rewind the paper into narrower widths, and into rolls of smaller diameter and more uniform hardness. This operation is becoming more and more important, owing to the increase in use of roll printing machines, automatic wrapping machines, counter rolls, gummed-paper tape, etc., the consumption of paper for such purposes being enormous.

9. The Rewinder.—The **slitter** operates either by the **shear method,** in which the paper is fed between revolving circular disk knives, or by the **score-cutter method,** in which the paper is fed between a V-shaped disk knife and a smooth, hard cylinder. The *score-cutting operation* is shown in Fig. 2. Here the paper is taken from reel A, passed over the guide roll G, and then between the circular disk knife S and the steel cylinder W_1, where it is slit; it is then rewound at P on a shaft or core by surface contact of the paper with rolls W and W_1. Riding roll R serves to keep the tension even.

A pair of *shear slitters* is shown at *S*, Fig. 3. Here a set of these disks, carried by two shafts extending across the machine, slits the paper after it passes the tension roll *T* and the first guide roll *G*. The slit paper may pass over the rear of the back roll

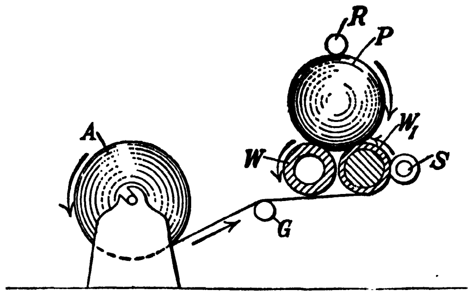


FIG. 2.

W_1, or up between *W* and W_1, as in this case. Note that shafts *E* and bearing rolls *W* and W_1 are duplicated, so that 2, 3, or 4 rolls may be wound independently.

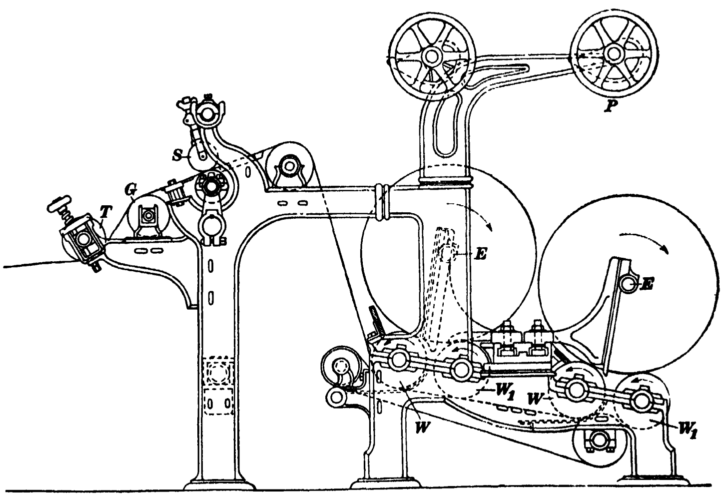


FIG. 3.

The **rewinding** may also be done in two ways. By the first method, the *center rewind*, one or more shafts carrying the rewound rolls are driven by a slip-belt or friction-clutch arrangement. The slipping of the belt or clutch allows the shaft to

slow down as the diameter of the paper roll increases, thus keeping the linear speed of the paper constant; the tension of the paper may be controlled by a brake on shaft of reel A, Fig. 2. By the second method, the *surface rewind*, the rewound rolls are formed side by side on a single shaft. In Figs. 2 and 3, the rewind shaft E rests on the rolls W and W_1 and turns, according to their speed, by friction contact. As the paper is run onto the rewind shaft, the shaft itself rises, so the surface of the rolls being formed on it is always in close contact with the rolls W and W_1, which are driven at constant speed. The latter of the two methods is preferable, especially in the case of narrow coils that will not stand alone after having been built up to any considerable diameter. The diameter of the rewound roll depends on the customer's requirements: in connection with printing papers, the diameter is determined by the dimensions of the printing press, and is usually from 30 to 36 inches.

10. The Automatic Rewinder.—The **automatic rewinder,** a development of the small rewinder, is comparatively new in this field, and it is perhaps destined to become an important piece of machinery for certain types of work. It is used for winding small rolls, such as shelf roll for household use, and for other small rolls. It reduces a parent roll, of proper width, into small rolls containing from 10 to 300 ft. of paper, as required, the different lengths being determined by interchangeable gears, somewhat like the gears used to determine the different lengths on the sheet-cutting machine.

The great advantage of this type of rewinder is the saving of time in changing cores. The empty core is picked up and thrust into the place of the filled core as the web of the finished roll is cut off, there being no shut-down for the transfer.

11. New Type of High-Speed Winder.—This rewinder, shown in Fig. 4, is placed after the reels on high-speed paper machines. The following is a description of the principal parts:

The front drum A is grooved helically to assure separation of the rewound rolls, and also longitudinally to remove wrinkles in the web. At the beginning of the run, rewind shaft B lies on top of the paper in the valley between the front and rear winding drums. The slit paper is pulled forward over the rewind shaft; the slit paper is tucked tightly around the rewind shaft, and the

unslit end is torn off. The winder is then off to a good start. The riding roller *C* is a driven roller, and it is automatically counterweighted (see *E*) so that maximum pressure is applied at the start of the run, when it is needed. Bevel gear *D* drives the riding roller from the riding-roller drive shaft *F*, which is driven from the main drive shaft *S* through bevel gears. Weights suspended from winding-shaft counterweight cam *G* counterbalance the weight of the rewind shaft evenly from start to finish

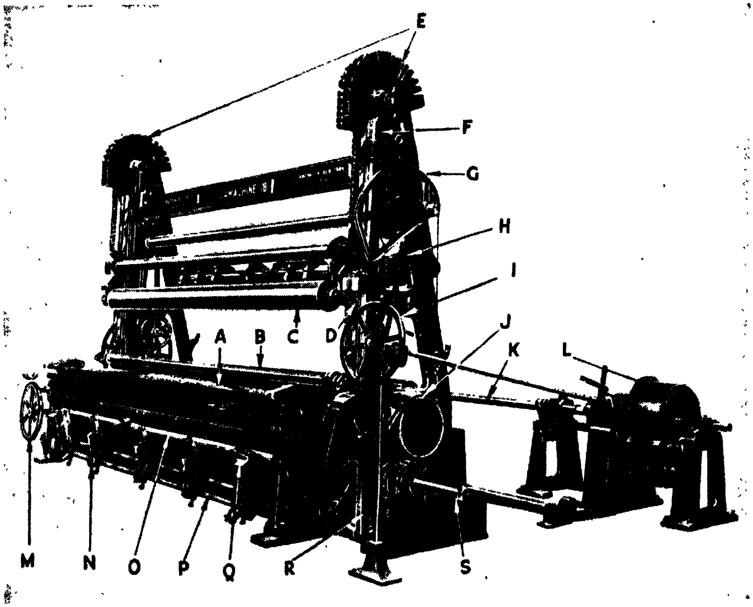


FIG. 4.

of the run. As the roll grows in size, the riding roller *C* rides on top of the roll, which permits the weights *E* to spill over the back of the machine, and these weights, pulling on the suspender chains, counterbalance the weight of the riding roller as the roll of paper grows in diameter. Uniform density of the rewound roll from core to circumference is thus assured. The hand wheel on the opposite side of the machine operates the winding-shaft carriage chain *H* through sprockets, to raise or lower the rewind shaft as required. Hand wheel *I* enables the operator to shift the mill roll from side to side as desired. The brake *J* is applied

by means of the brake-control hand lever *R*. The mill-roll brake drum and band *L*, on shaft *K*, is controlled by foot treadle or hand lever as required; the control may be located at either side of the machine. The slitter support beam hand wheel *M* throws all slitters in or out of action simultaneously by a turn or two of the hand wheel. The mill-type slitter wheel *N* carried on slitter support beam *P*, is an improved unit, the slitter wheel being mounted on an axle having a ball bearing at each end. A wing nut provides for regulating the pressure as required through springs on each individual slitter wheel. The slitter platen roll *O* consists of highly polished hardened-steel sleeves, butted together on a core shaft. The paper passes over this roll, and the cutters press through the paper against the roll. The trim guides *Q* are placed alongside the end cutters and deflect the trim onto the floor. The brake-control hand lever is shown at *R*, and *S* is the main drive shaft. Provision can be made to drive by belt through a special Cameron clutch, by slip belt, direct-drive motor, or by any other approved method.

CUTTING THE PAPER

12. Description of Cutter.—Referring to the cutter illustrated in Fig. 5, it consists briefly of the following parts: (*a*) the reel stand, to hold the rolls or reels of paper *A*. This is an iron frame *B*, with suitable bearings *P*, for holding from 1 to 50 rolls of paper (in one waxed-paper factory, there is a reel stand accommodating 100 rolls). The bearings can be moved (adjusted) so as to keep the paper running true, without wrinkling and in close alinement when superimposed webs are being drawn into the cutter from the rolls on the reel stand. (*b*) The cutter proper *E*, which has a revolving knife *F*, mounted on framework *E*. A cutter with one revolving knife is called a *single-type cutter*, and one that has two such knives is called a *duplex-type cutter*. The web of paper is cut off crosswise to its line of travel through the cutter by the revolving knife (with a shearing action, like a pair of shears) by coming in contact with the stationary bed-knife *G*. (*c*) The revolving circular-disk slitter knives *H*, which slit the paper in exactly the same manner as on the rewinder; these knives are adjustable to any required width of web.

The paper web is pulled through from the reel stand by the squeeze roll *I*, the pressure of which is adjusted by screws and lock nuts *J*. The latest type of squeeze roll has on it a rubber covering, applied worm fashion, instead of the older type of felt covering, which was tacked onto the roll. The rubber covering eliminates the danger of tacks working loose and marking the web. (*d*) Sheet lengths are controlled in either of two ways: first, by shifting a belt on cone pulleys; second, by means of an expansion pulley *K*, as shown in Fig. 5.

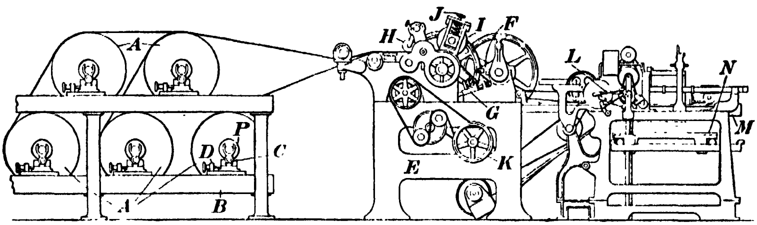


FIG. 5.

13. Mounting the Reels.—The reels of paper *A*, Fig. 5, which have been machine finished or supercalendered, are mounted on the reel stand *B* by means of a chain fall, rope tackle, or air or electric hoist, the air or electric hoist being the quickest. The reel is attached to the hoist in various ways: sometimes broad straps passing around the paper are used; sometimes iron hooks are caught into the ends of the reels on which the paper is wound, or onto shafts that pass through cores on which the paper is wound. In the latter case, a spreader bar should be used to avoid damage to the edges of the paper. The hand wheels *D* regulate the paralleling of the rolls of paper on the reel stand; hand wheels *C* regulate the alinement of the edges of the rolls of paper on the reel stand; friction is applied by another hand wheel, which tightens a strap around a collar on the reel shaft.

The *number of reels* of paper on a reel stand varies, from 8 to 12 being usual; for light tissues, 24 reels are common. When a reel is finished, the empty core and shaft or reel are removed, and a new reel is put in its place, or else the original set of reels is run off to the end of the last reel. To avoid breaking the sheets, the other unfinished rolls may be rolled forward and the new roll placed at the end. The number of reels that can be cut simultaneously will depend on the quality and basis weight of the

paper. When cutting the lower grades of paper, a larger number of reels is generally cut than when cutting the higher grades; because, in most cases, the lower grades are not so tough, and they are therefore easier to cut: also, it is not so important on the lower grades that the paper be so closely matched for color, finish, etc. In those cases where a bad roll has been made in a run of paper, it is better to cut it separately, possibly slitting and rewinding it first. A great loss of time occurs in cutting a bad roll along with good rolls; in such case, with cutting and piling equipment now available for web speeds through the cutter of 400, 450, or higher, ft. per min., it is not a costly operation to sheet from a single roll at a time. The same high-speed equipment is adaptable to multiple-roll cutting, as well as to single-roll cutting. When loading reels for multiple cutting, care should be taken to have the reels come from the same section crosswise to the paper machine, if the web were slit and rewound after it came from the paper-machine room.

14. Adjusting the Cut.—The speed of the paper web passing into the cutter is constant, the variation in the length of the sheet cut being secured by altering the peripheral speed of the revolving knife. For ordinary lengths of sheets, expanding or cone pulleys are used to change the knife speeds; but, for wide variations in speed, change gears are used. With some types of variable-speed transmission, large variations can be made without change gears. The shorter the sheet to be cut the faster the knife must revolve, and vice versa.

15. Trimming the Sheet.—A *trimming,* or *shaving,* is generally taken off the edges of the webs, which are always rough and usually dirty, particularly when the full-width, or jumbo, reel is brought to the reel stand from the machine room; this trimming should not be more than $\frac{3}{4}$ in. wide, so as to keep the amount of cutter broke down to a minimum. It is very important to watch the trimming on the cutters, since a large saving may be made in checking up the extra width allowed by the paper machine.

16. Laying the Paper.—The old-fashioned method, now seldom used, is to catch the sheeted paper by hand from the cutter. The operative, sitting beside a low table, catches the sheet paper and squares it against a fixed corner as it comes from the cutter. After leaving the knife, the sheeted paper falls on a traveling

felt, or series of tapes, which carries it to the tables where the operatives are seated, these tables being in the position now occupied by the layboy N, Fig. 5. When a number of sheets are being cut crosswise to the web, the tables are usually arranged so that the outside sheets fall into the position closest to the cutter, onto tables located nearer the middle of the web. This arrangement permits all the operatives to sit in such a manner that the paper they are catching passes in front of them, across the body, in which position they can do their work with the least difficulty.

When the sheets are to be *quire folded*, the custom is to cut from 24 reels simultaneously; and each drop of a folding blade on the *quire folder* forces a packet of 24 sheets down between the rollers to a set of tapes that convey the folded quire to the operatives, who stack the folded quires manually on tables. A quire folder is located in front of the cutter, the same as the layboy is on a cutter, the product from which is not to be mechanically folded. By disconnecting the folding blade, packets of sheets may be run through the quire folder and stacked flat on the tables. It is possible to locate a layboy in front of the quire folder so that the flat packets pass through the folder and into the layboy, to be jogged and piled into high stacks, instead of being deposited from the folder onto tables for manual stacking. Using a layboy enables the mill to permit less trim on the sheets, as the high piles are jogged evenly by the layboy. But when operatives build up the sheets into high piles by hand, it is necessary to even up all four sides of the stack by subsequent trimming on ream cutters.

17. Automatic Layboys.—Most cutters are now equipped with **automatic layboys** or **jogging boxes,** the latter being commonly used to catch sheets from cutters that run continuously at the end of board and pulp machines, and to sheet the web as it is delivered by these machines. The use of automatic layboys reduces the crew needed to cut and pile sheets, and it also increases the operating speed. A recently perfected device delivers the sheeted paper in *overlapped* relation from the knife to the piles in the layboy, which makes speeds of 400 to 450, or higher, ft. per min. practical on the cutter, as compared with the former speeds of 200 to 250 ft. per min. when the sheeted paper was delivered in *tandem* relation. The **Mamco overlapping**

delivery system is shown in Fig. 6, and the **tandem delivery** system in Fig. 5. Fig. 6 shows the two separate sets of tapes that convey the sheets from the cutter. The first set *A* travels at high speed to get the paper quickly out of the path of the revolving knife and drop it off, under control, to the low-speed set *B* and onto the piles. Fig. 5 shows only one set of tapes, the packets passing one at a time, with space between them, to the piles. Either tape system delivers the sheets to the pile tables, which are lowered automatically by the layboys. This lowering is done by contact fingers, which operate screws or chains to let the pile tables down as the sheets fill up the skids used on the

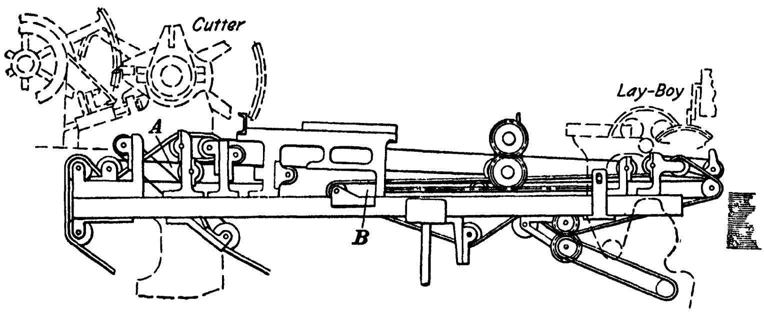


Fig. 6.

layboys to receive the sheets. The top of the piles of sheets is always at the same height, the pile table being lowered automatically. As they come onto the piles, the sheets are jogged mechanically to make the edges of the stacks even.

In some mills, the sheets are sorted as they come into the piles; but this means slower speed on the cutter and the layboy, and the trend now is toward highest possible cutter and layboy speed, with overlapped delivery of the sheeted paper, and sorting done as a separate operation from the piles after they have been taken away from the layboy on lift trucks. Speed is governed by sorting, or by the momentum with which the cuts of paper come onto the piles. The overlapped principle of delivery slows down the momentum, and it makes very fast speeds possible without wastage of paper.

18. Counting and Tagging Reams, Quires, etc.—The old-fashioned system of counting sheets mentally, and putting markers between reams, quires, etc., manually, has been replaced

in many mills by **Mamco automatic counters and markers.** These counters and markers, Fig. 7, are used on single or duplex cutters and layboys; they count from a single roll at a time up to the capacity provided for on the reel stand.

When beginning a job, the handle *A* is set into the hole in the counter housing *B* that is numbered to correspond with the number of reels of paper being cut from a job. During the course of the work, if a reel runs out to its core, or new reels are added to the reel stand in excess of the original loading, the

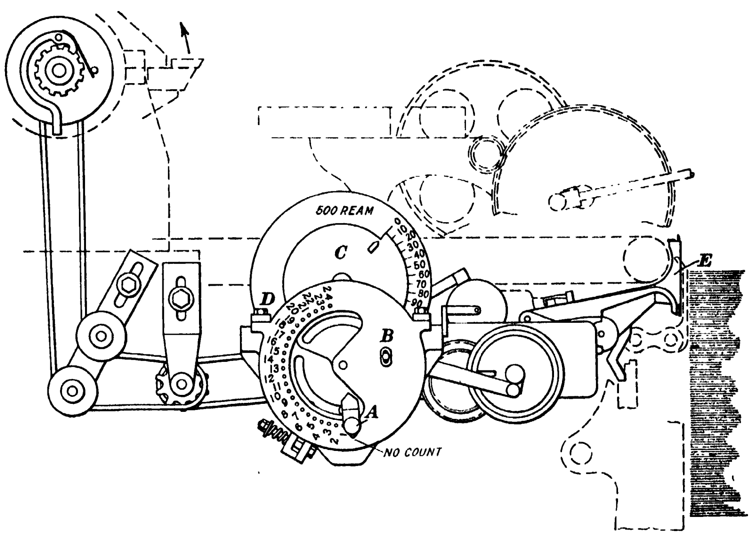


FIG. 7.

handle *A* is moved to a hole numbered to correspond with the revised load on the reel stand. This shifting of the handle is accomplished by the cutterman without stopping the machine. The upper count dial *C* is changed for different count divisions. Loosening two cap screws *D* allows removal of the dial and the placing of another dial thereon. When the sheets delivered to the piles in the layboy add to the predetermined count division, a bell rings, and at the same time a tagging head *E* inserts a tag that marks this division noticeably. A tag is put into the back of each pile being stacked by the layboy at the time.

When the number of reels being sheeted from does not divide evenly into the division being tagged, the individual tags will not

mark off exact divisions, but will tag in a cycle. This is because the tags must go into the piles between packets of sheets and not between individual sheets of a packet. For example, cutting from three reels and dividing into reams of 500 sheets. Here the first tag goes in at 501 sheets, the second at 1002 sheets, and the third at 1500 sheets; and the cycle is then repeated. The contents of three reams is thus tagged correctly; but two of the three reams are each one sheet over, and the third is two sheets under. To avoid this, some mills use a *full-count dial* that always gives the same number of sheets per tagged ream as came in the first ream of the cycle. In the foregoing example, the full-count dial will always tag 501 sheets.

19. Size of Crew.—When sheets of paper are caught manually, the crew usually consists of one man to supervise the cutter; a helper, on wide cutters, to take care of loading reels onto the reel stand and to assist the cutterman in setting knives, etc.; and an attendant for every pile being stacked crosswise to the web. Where automatic layboys are used, no attendants are needed for the piles of sheets. If counting and tagging of count divisions are done with a counter and marker, no attendants other than the cutterman and helper are needed.

If the sheeting, piling, counting, and tagging operations are conducted from the drums of a reel stand in front of a paper machine or air dryer, the crew handling this also constitutes the crew for the cutter, layboy, and the counter and marker. This system is proving popular.

20. Cutter Knives.—The life of a cutter knife is dependent on the nature of the materials being cut, the thickness of the web, and the hardness of the sheet itself. A filler that puts grit into the paper is especially hard on the knives.

21. Number of Sheets Cut Crosswise to the Web.—The number of sheets cut across the web varies from 1 to 15. On rayon-pulp work, 10 or more piles can be cut and piled on the layboy, Fig. 5, simultaneously. The average knife length of cutters ranges between 85 in. and 130 in., but the extremes run from 30 in. to 220 in. The number of piles stacked by layboys averages 3 or 4, though some machines stack only one pile at a time, while others stack as many as 15 at a time. When delivering packets tandem, it was formerly the custom to use wide

cutters, in order to get big production. With the perfecting of the delivering of packets of sheets overlapped, narrower cutters give big production; for which reason, mills use them to avoid wrinkling, knife vibration, etc., which were common on wide cutters.

Cutter production varies greatly. It is estimated that on tandem-delivery equipment, one ton of sheets can be cut per 8-hour day for each 5 inches of cutter knife length on a roll set of 25-lb. paper (kraft basis). On overlapping delivery equipment, this tonnage can easily be doubled. To estimate tonnage on any other work, the number of rolls and the basis-weight load must be figured proportionately.

22. Cutter Broke.—**Cutter broke** consists of trimmings, dirty paper on the outside of reels, wrinkled paper, and the broke made on the cutter itself, which is caused by breaks. The maximum amount of broke should not exceed 2 per cent. The total amount of broke can be considerably reduced by careful handling of the reels, by properly flagging all breaks in the reels, and by making certain that the reels are set squarely, so no wrinkles will form. In this connection, allowance should be made for such reels as are harder on one end than on the other end. Should there be considerable difference in hardness crosswise to a set of reels, it would be preferable to have each of the set come from the crosswise section of the paper machine, since it would facilitate getting the proper tension, and would help to eliminate wrinkles from the web.

23. Cutter Drive.—The cutter should have an adjustable-speed drive, because some papers can be cut more easily than others. For this purpose, an adjustable-speed electric motor on each cutter is the best form of drive.

24. Angle Cutters.—**Angle,** or **diagonal, cutters** are used chiefly for cutting envelope paper. These machines cut the paper into sheets whose edges make angles other than 90°. This is accomplished either by setting the knife diagonally to the direction of the web or by lifting one end of the knife in a vertical plane until it will cut to the required angle, in which case, as the knife descends, the speed of the paper carries the paper past the point where the edge of the blade first touches it, thus making a diagonal cut.

25. Duplex Cutters.—The machine shown in Fig. 5 is a **single cutter,** *i.e.*, it has only one revolving knife. When it is desired to cut some strips to one length and others to a different length, a duplex, or double, cutter is used. A **duplex cutter** has a second revolving knife and bedknife, which are driven separately from the first set; and they are controlled as to speed by an independent set of pulleys.

A duplex cutter is sometimes desirable in obtaining a more economical use of the maximum width of the paper web. For example, if a machine is making paper to be cut, say, 22 by 34 in., and the maximum width of paper that the machine can make is, say, 102 in., the operator cannot get three strips 34 in. wide, because $3 \times 34 = 102$ in., and there must be an allowance on either side for trimming. Four strips 22 in. wide will use only $4 \times 22 = 88$ in., or less than 86% of the machine capacity. But, by slitting the web into *three* strips 22 in. long (crosswise), and one 34 in. long, the total width used up is $3 \times 22 + 34 = 100$ in., which leaves 2 in. for the trimming. There are, of course, occasions when this changing of the grain or direction of the paper on the machine with reference to the long edge of the sheet, would not be permitted.

26. Hazards.—All gears should be protected by guards; these should be efficient, and be easily removable for necessary adjustments to the machine. A single web of paper should be fed into the cutter manually before operation begins; then, after the power is on, the other webs may be fed in.

SUPERCALENDERS

MECHANICAL DETAILS

27. Purpose and Description.—**Supercalenders** are used for the purpose of putting a higher finish, or gloss, on machine-dried paper than can be obtained on the paper machine itself.

The supercalender, which is similar in general construction to the calender described in the Section on *Papermaking Machines*, Section 1, consists of a series of rolls *R*, Fig. 8, from 3 to 12 in number, and arranged in a vertical stack. Power is applied to the bottom roll, or, sometimes, in very large calenders, to the

third roll from the bottom; and it is transmitted from roll to roll by the friction of contact.

In addition to their use in connection with machine-dried papers, supercalenders are being used more and more in recent years to finish loop-dried and air-dried papers, these being previously hung or pole dried, and finished on sheet calenders or platers.

Driving on the third roll from the bottom is distinctly a European practice. There is a certain amount of slip in rolls that are

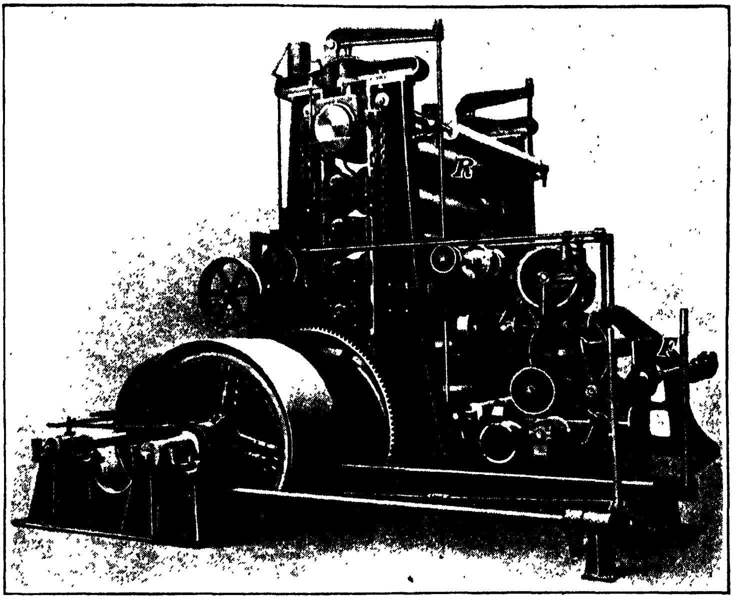


FIG. 8.

driven by surface friction, and the drive should be applied in a manner to make this slip progressive and uniform. When the drive is on the third roll from the bottom, there will be a certain slip in the rolls above, and an entirely different amount of slip on the roll immediately below it. The result of this is a tendency to cause the paper to run baggy in the lower part of the stack, producing wrinkles, cuts, and numerous breaks at the lowest nip. With this arrangement, it is also very hard to keep the second and fourth rolls from the bottom in good condition; and, since much of the finishing is done at these points, there is a very serious objection to a type of drive that limits the finishing efficiency of

the calender in the lower nips. The third roll from the bottom is relatively small in diameter; and, in running heavyweight papers, there is a noticeable tendency of the roll to spin, rather than to drive the rolls above and below it by surface friction with any degree of uniformity.

When driving on the bottom roll, the slip of all the rolls above is progressive and uniform. The upper rolls run successively slower, so the sheet, as it lengthens out under pressure, is taken up as it goes through the stack, with no tendency to run baggy and fall into wrinkles or cuts. Numerous drives on existing installations of both English- and German-built supercalenders have been changed from the third roll to the bottom roll, and the results have been very satisfactory.

The paper is fed from a reel stand *F* and threaded between the rolls, additional pressure being applied on top bearings of the stack, to give the desired finish; the paper is then brought back to the reel stand and wound on a core. The bearings are usually water cooled, especially in the case of the top and bottom rolls, and the journals are able to slide up and down in the stack grooves. Roller bearings are often used on the top and bottom roll journals. The reel stand is usually of the revolving type, with reversible power connection for rotating it in either direction, both the finished and unfinished roll being on the same stand.

28. The Rolls.—The rolls used are of three types, chilled iron, cotton, and paper. Usually, chilled-iron rolls alternate with either cotton or paper rolls, but sometimes the iron rolls are used alone. Sometimes one of the alternating iron rolls is left out, so that both sides of the paper may come into contact with the same amount of iron and fiber, thus reducing two-sided effects. Iron rolls alone do not give so even a finish as alternate kinds, *i.e.*, they do not flatten out the paper and smooth all parts of it; they smooth the thick places but not the thin ones. Fiber rolls will fill in in these places and give the whole surface a smooth finish. Paper rolls give a higher finish than cotton rolls, and paper rolls stand up longer than cotton rolls. Fiber rolls are made of disks of paper or cotton, squeezed together under great pressure, and then turned to a true cylinder.

Paper rolls are used for bag, wrapping, waxing, high-grade news, magazine, and book papers, and for sulphite bonds and

some grades of writings; they should always be used when a sheet is to be hammered down as well as finished. Cotton rolls are used on the better grades of writing, bond, ledger, special book, and most coated papers; they should always be used when a sheet is to be smoothed and its bulk retained.

The initial pressure exerted by the rolls on the paper is caused by the weight of the rolls; additional pressure is added by means of levers and weights or by levers operated by power. This extra pressure is applied to the top roll, which, in turn, exerts pressure on the rolls under it, the latter being free to move vertically in the grooves of the frames.

29. Threading in the Paper.—The roll about to be calendered is mounted on the reel stand; the paper is then threaded into the nip of the two top rolls, then down through the stack, back and forth, very often coming out around the bottom roll, and back to the reel stand, where it is wound on a core, though many mills prefer to lead the paper direct from the bottom nip to the reel. Two speeds are used for the rolls, the **lower, or threading-in speed** (20 to 100 ft. per min. surface speed—usually not over 50 ft.), and the **higher, or operating speed** (400 to 800 ft. per min.). It is very important that the acceleration from low to high speed be smooth (constant), so as to produce an even tension on the paper and not cause it to break. The converse is equally important, in order to slow down uniformly and deal gently with torn edges and weak places.

The speed changes are obtained in several ways, in accordance with the type of drive.

TYPES OF DRIVES

30. Group, or Shaft, Drive.—The group, or shaft, drive was formerly employed universally; it is shown diagrammatically in Fig. 9, where *A* is a pin or friction clutch, *B* is a friction clutch, *C* is the low-speed pulley, and *D* is the high-speed pulley. Pulley *C* is put in motion, and the motion is transmitted to the bottom calender roll *R* through clutch *E*, gears *G*, and clutch *A*; this causes roll *R* to turn at low speed, pulley *D* turning idly on its shaft. After threading in the paper, clutch *B* is thrown in, clutch *A* being automatically thrown out at the same time, and the calender comes up to full, or high, speed. The large gear *G*

then turns idly until the clutch E is thrown out. The high speed must be a compromise between the highest speed *any* paper will stand and some slower speed that is suited to the weakest paper. The rods H operate the clutches.

In the latest belt-driven calenders, the tendency is toward the use of the single-belt drive, which is shown in Fig. 10. Here gear C, driven at reduced speed through gear D, takes the place of the low-speed pulley C in Fig. 9. Pulley F is belted direct from the main shaft, and no countershaft is required.

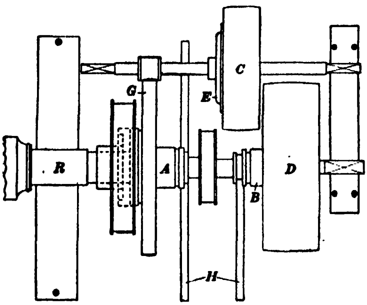


FIG. 9.

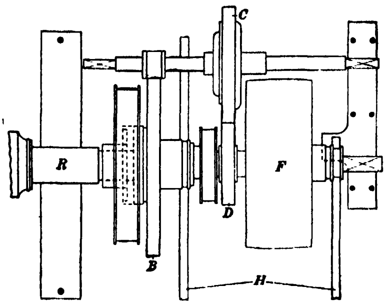


FIG. 10.

31. Engine Drive.—Individual variable-speed engines may be used; but this means long lines for the drive, and this type is not common. A two-cylinder engine is a necessity for this drive; but, even then, a uniform torque (turning moment) is not obtained.

32. Motor Drives.—There are several forms of motor drives. A two-motor drive is shown in Fig. 11, in which A is a pin clutch, and B is a gear on the same shaft, driven through reducing gears and clutch C by motor M. To start this drive, the small motor M is started up by closing the circuit breaker, and clutch A is thrown in, the calender being then on low speed. After threading in the paper, the controller of the large motor N is advanced; this puts the calender on high speed, and it automatically throws out clutch A at the same time. In the latest installations, the large motor N is of the variable-speed type, thus permitting the use of the maximum speed suited to any class of paper.

In a second type of motor drive, Fig. 12, the two motors are replaced by a single motor M, the drive being through gears A, D, C, B for the low speed. After threading in the paper, clutch

E is thrown out, *F* is thrown in, and the calender is brought up to speed, with the motor and controller. The procedure in this drive is somewhat similar to that described in Art. **30.** The drive is not, however, economical of power, since the large motor is operated on low-power requirements a part of the time.

A third form of motor drive has a single motor, geared direct to the shaft, which has a wide range of speed, all speed changes being obtained by moving the controller of the motor. This is a very convenient device for the operator, but it is an expensive

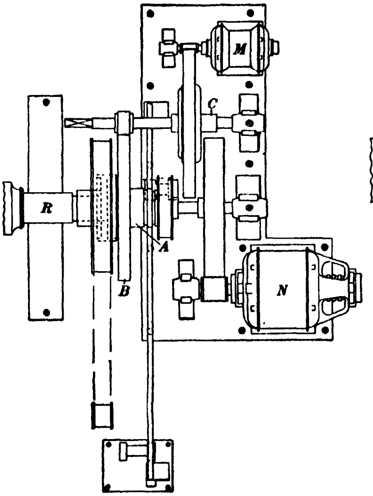


Fig. 11.

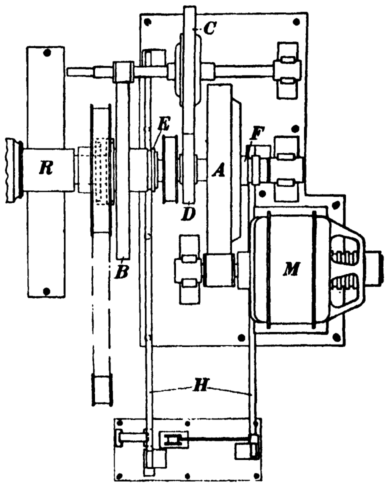


Fig. 12.

installation. In order to operate successfully, a direct-current motor is usually selected; because wide speed changes cannot be obtained with an alternating-current motor without introducing considerable resistance into the control, and this means power loss. However, a form of motor drive is now being successfully used with alternating current. With a current of, say, 60 cycles, arrangements are made to operate the motor on 6 cycles at low, or threading-in speed, and on 60 cycles over the usual range of production speeds. The drive works well, and it is particularly effective where a number of calenders in the same mill are so driven.

The motor drive is preferable to the belt drive; and the two-motor drive is the best form, on account of the better mechanical

features, less current consumption, and the greater smoothness of operation that is being obtained when picking up from low to high speed. However, constant progress is being made, and the drive of tomorrow will be a much better mechanism than the drive of today.

OPERATION DETAILS

33. Power Requirements.—The power required by a supercalender varies with the thickness of the paper to be run, the kind of rolls used, the size of the machine, the pressure on the rolls, the number of nips, the speed, and the kind of bearings used. Usually, on book papers, from 2 to 12 hp., depending on the width and weight of the calender, is required for threading in the paper, *i.e.*, for low speed; and from 0.5 to 1 hp. per inch of width of paper on a 7- or 9-roll machine, when running at the operating, or high, speed. With heavy rag papers that require a high finish, and for other special grades, 1.5 hp., or even more, per inch of width of paper may be necessary.

About 80% of the power is consumed by the friction of the rolls, and the remaining 20% is taken by the paper. The thicker the paper the more power required, cardboard requiring 25% more than an ordinary grade of book paper. Iron rolls take somewhat less power than fiber rolls, and roller bearings are claimed to take 30% less power than plain bearings. The power required varies almost directly as the surface speed of the rolls. It is very important that the bearings be well oiled, since lack of oil may increase the power consumption 10%. Automatic oiling is very desirable on supercalenders; it insures sufficient lubrication and saves oil.

34. Factors That Influence the Finish.—The finish of the paper depends on the material in the sheet, the kind of rolls, the temperature of the rolls, the moisture content of the paper, and the pressure on the paper. Paper containing a clay filler takes a very high gloss. As stated before, fiber rolls give a smoother and more even finish than all-iron rolls. If the rolls be steam heated, an exceptionally high finish can be obtained. Moisture in the paper has the same effect as heat, and moisture and heat act in the same way as they do on cloth when it is being ironed. Both moisture and pressure are required to get smooth-

ness and gloss on the paper, which is usually dampened by applying steam directly on the paper while it is being run on the supercalender. Increasing the pressure on the rolls increases the finish; but it also weakens the paper, and it will eventually blacken it, especially if the moisture content be high.

Some calender frames are provided with means for lifting one or more rolls at the top, in order to reduce the amount of finish, or for separating iron and cotton rolls when not in use. For increasing the pressure, a set of compound levers is provided.

35. Care of Rolls.—If the rolls are to operate at their maximum efficiency, it is very important that they be carefully watched. If a narrow deckle (sheet) is run for the first time and a change is made to a wide deckle, without smoothing the roll with sandpaper, a ridge will be formed at the place the narrow deckle ended, and this will mark the paper. Sandpaper is held against the roll while the roll is running, until all marks are eradicated. No. 1 garnet paper is good for this purpose, but fine grit may be better in some cases. Any dirt or lumps of broke going through the roll nip will tend to mark fiber rolls, which will then transfer the mark to all the paper going through the calender. Great care must be taken at all times to keep foreign matter from going through the rolls, since this shortens the life of the rolls and decreases their efficiency. For the sake of safety, apply the sandpaper on the out-running side of the roll.

The use of **blow** or **fly rolls**, particularly on cotton-roll stacks running coated papers, is steadily growing. These rolls are carried in universal adjustable bearings, attached to tee slots on the inside of the calender frame housings. The sheet of paper is carried away from the cotton roll, over the fly roll, and back into the next nip. This procedure keeps a mark or mar in the surface of the cotton roll from striking the paper twice in the same place. The use of fly rolls also permits the running of a fiber roll having a marked surface for a longer time than would otherwise be possible without resorting to scrubbing and sandpapering.

On every change of deckle, the rolls should be sandpapered, in order to obtain a uniform surface. When the rolls show definite signs of wear, such as pits or marks, they should be taken out; if the rolls are of chilled iron, they should be ground; and if of

cotton or paper, they should be turned. When cotton rolls are turned, the last cut should be taken with a diamond tool, as no steel tool will keep its edge long enough to go across a roll of this kind; and if a steel tool is used, the end of the roll will be roughened by the blunt tool. When the rolls have been turned up, they are installed in the calender and scrubbed with sandpaper, to give them the necessary smooth finish. Spare rolls are always kept on hand to replace the one being turned, the latter roll, in turn, becoming the spare roll.

36. Friction-Glazing Calender.—**Friction glazing** is employed to get a very high finish on paper. This type of finish is usually

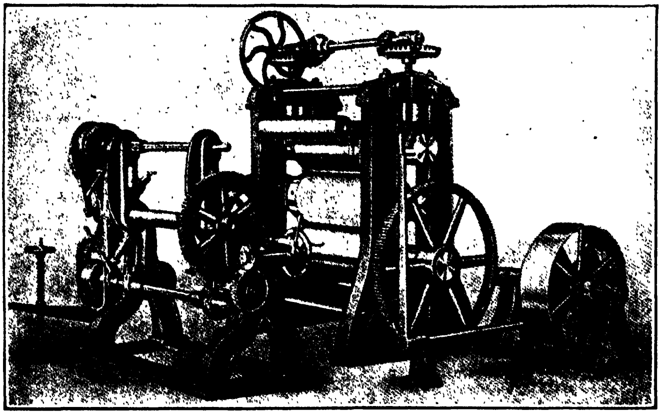


FIG. 13.

confined to coated paper, in rolls, mostly paper that is coated on but one side. The principle of the operation is the feeding of the paper between rolls revolving at different peripheral speeds, these speeds being obtained by means of different gear ratios on the rolls. This calender tends to impart a very high finish on one side of the paper. According to Cross and Bevan, a one-sided effect of extra high finish may be obtained (when two rolls are used, one being a large paper roll and the other a small iron one) by rubbing wax on the iron roll. Most American mills making papers with an extremely high finish on one side add wax to the mixture used for coating that side. Friction calenders are largely used in finishing coated box-lining papers, waterproof papers, bronze and silver papers, etc.

The usual arrangement of the friction calender is three rolls; the bottom roll is chilled iron, the intermediate is cotton, and the top roll is chilled iron and is bored to admit steam. In the older machines, the friction was produced by driving the rolls at different speeds by means of a belt drive. The belt drive has been superseded by the silent chain drive, or by direct gearing, as much more even friction results when no slip occurs in the drive and the speed of the driven roll is constant.

In the friction calender shown in Fig. 13, the pressure on the paper is adjusted by a screw instead of by levers. The paper from the unfinished roll passes from an unwinding stand, similar to *F*, Fig. 8, fitted with brakes on the bearings, over two guide rolls, through the calender, and to the rewinding stand, where the core is on a shaft driven from a pulley on one end of the top roll. The width of a friction calender is from 25 to 40 inches; wide machines have not been found to be very satisfactory, because the finish is not as regular as that imparted by narrow calenders. It will be noted that pressure is increased in this machine by bevel gears instead of levers, as in Fig. 8.

37. Number of Laborers Required.—Two men, one the operator and the other the helper, are required to operate a supercalender. These two men are responsible for the whole calendering operation, from the mounting of the reels to the delivery of the finished paper to the cutters.

38. Calender Broke.—Broke on the calender is principally caused during the period when the speed is changed from that of the threading in to that of full operating speed, *i.e.*, from low to high speed. This can be minimized by having a type of drive that changes smoothly and picks up uniformly. There are many other causes that make for broke, chief of which is the condition of the paper when it is sent from the paper machine, the number of breaks in the roll, and whether each break has been properly flagged. The flagging of breaks gives the operator time to stop the supercalender, in order to make the necessary repair before the break goes through the stack. Flagging of weak spots will permit slowing down the calender, so as to avoid breaks.

39. Safety Devices.—As on other types of machinery, all gears should be equipped with removable guards. On high stacks of calenders, it is important that the operator be given a good

railed-in platform to stand on when threading in the paper. He should also have broad steps leading to the platform, since excessive reaching to thread in the paper greatly increases the chances of slipping, and these chances are decreased with broad steps. There is then very little danger in threading in, as the operator has a firm foothold and slow speed is being used. But if an accident should occur, means should be provided for striking out the calender quickly. With electrically-driven calenders, push-button switches, located at convenient points, provide excellent safety stops. Finger guards should be provided at each nip.

LATER FINISHING OPERATIONS

FINISHING LOFT-DRIED PAPERS

40. Peculiarities of Loft-Dried Papers.—As explained in a previous Section, the higher grades of bond, ledger, and linen-finish papers are loft dried before finishing. Such papers are in sheet form, and they undergo some finishing operations that differ from those applied to machine-dried papers. However, when papers are air-dried on slat or festoon dryers, they may be finished on modified web supercalenders.

Loft-dried paper in its rough state has a harder and rougher surface, a more cockly appearance, has a greater tendency to curl at the edge, and is much stronger than machine-dried paper. These peculiarities are due to the fact that it receives its final drying free from tension and from the smoothing effect that is given by the paper machine.

CONDITIONING OPERATIONS

41. Reasons for Conditioning Paper.—The finishing of bond and ledger loft-dried papers generally consists merely of smoothing operations. However, before such paper is ready to be smoothed, it must undergo certain conditioning operations, to remove the curly tendency and hardness as much as possible, and to make it softer and more pliable, in much the manner that cloth has to be moistened before ironing.

42. Arranging the Sheets.—After removal from the loft, the paper (in sheets) is first carefully jogged and squared up. It is

now placed in piles that are from 6 to 10 feet high, preferably in a room supplied with air at about 55% to 60% relative humidity. The pressure of the pile, together with the moisture absorbed, tends to smooth out and soften the paper somewhat; and it should be allowed to condition in this way for a week or ten days. The paper should then contain about 7% to 7½% moisture.

43. Warming the Paper.—Just before going to the sheet calenders or other smoothing machines, the paper is wheeled into *ovens* (or a *heating room*), which are heated by steam coils, and the paper is warmed. The heat makes the paper pliable; and the paper should be heated long enough to drive the heat well into the load. Higher temperatures are required for lightweight than for heavyweight papers, as the latter do not cockle or curl so much. The following table gives the temperature to which paper should be heated in order to run well on the calenders; these temperatures are taken 4 inches in from the side of the load.

	Basis weight, pounds	Temperature Fahrenheit, degrees	Ream size
Bonds	30–40	105	24 × 36—500
Bonds	40–50	100	24 × 36—500
Bonds and ledgers	50–60	95	24 × 36—500
Bonds and ledgers	Over 60	90	24 × 36—500

The **basis weight** is the weight of a standard ream, which contains 500 sheets, 24″ × 36″. The paper under treatment may, of course, be any required size.

The temperature to which the paper is subjected in the ovens should be moderate, in order that the color of the paper shall not change, and that too high a temperature shall not be reached at the outside of the load when the inside is still cold. A temperature of 225°F. for papers below 50 lb. basis weight, increasing up to 260°F. for papers above 50 lb., will be found satisfactory.

It is important that the moisture content of the paper be right; from 6.5% to 7.5% is sufficient. Low moisture content causes curling at the corners, and high moisture content causes wrinkles. It is, of course, essential that the paper have a good formation, and that it be dried evenly on the paper machine.

44. Size of Loads Heated.—The number of loads heated should not be so great that a part of the paper cools off before it can be calendered. In general, the temperature of the paper will drop 8° per hour in the finishing room, and it should not be allowed to drop more than 10°. Hence, a load that can be run in 1¼ hours is the maximum load for the best results, unless it is more convenient to send some paper back to the ovens.

Under the above conditions, the time of heating will vary with **weight basis,** which is the weight of a ream of paper that contains a certain number of sheets of a particular size. What is called the **substance number** is the weight of a ream of 500 sheets, 17″ × 22″ (folio size); the **basis weight** is the weight of 500 sheets, 24″ × 36″; and the **standard ream weight** is the weight of 500 sheets, 25″ × 40″ (see Section 5). In any case, not more than 4 hours should be required to heat the paper; prolonged heating means deterioration of color.

45. Calender Production.—The heating room is provided with steam coils, and it is of sufficient capacity to accommodate all the paper to be heated. The table on the following page shows the average calender production per hour for various sizes and several grades of paper; it also specifies the standard load for each size, and gives the length of time that is normally required to bring the whole load to the required temperature, the room being held at the temperature mentioned in Art. **43,** and varying according to the weight of the paper.

SHEET CALENDERS AND BREAKERS

46. Purpose and Description of Sheet Calenders.—**Sheet calenders** are employed for finishing loft-dried papers, the degree of finish ranging from low to high; they are usually employed for calendering ledgers and writings. The **breaker,** Art. **51,** is a calender that puts a dull cockle finish on the paper; it is generally used for bond papers.

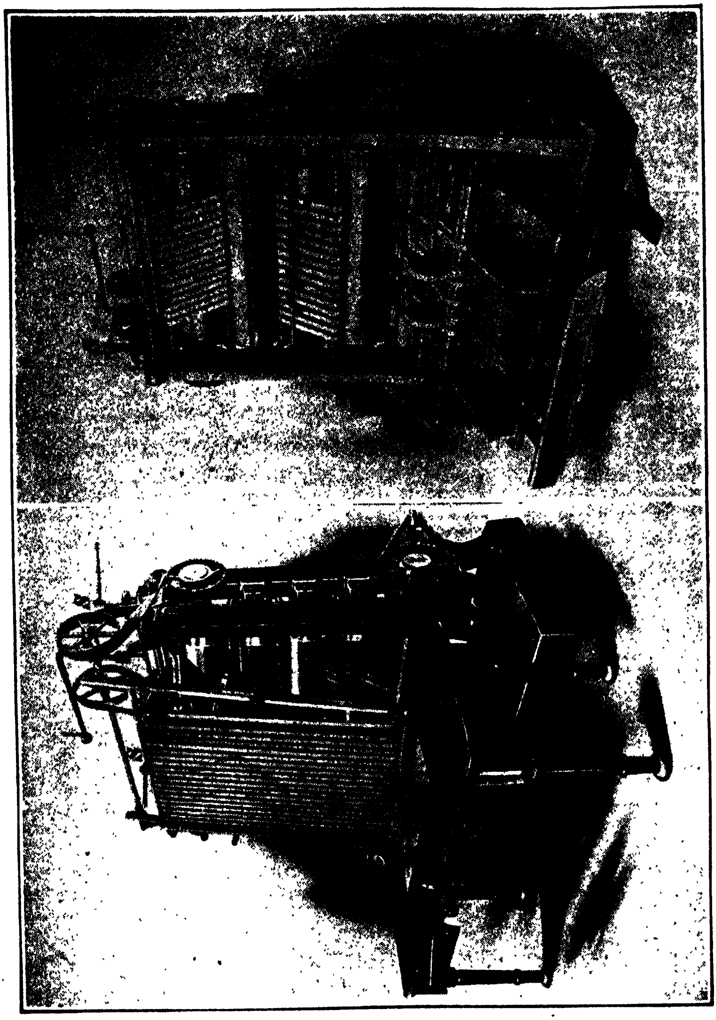
Sheet calenders consist of stacks of from 3 to 5 rolls, which are arranged in the same manner as those of the supercalender. The rolls are alternately of chilled iron and cotton, a chilled-iron roll being usually at the bottom of the stack, a cotton roll above it, and so on. The face of the rolls varies from a width of 28 in. to a width of 44 in.; but calender troubles multiply as the width

TABLE FOR HEATING PAPERS FOR SHEET CALENDERS

Grade	Basis weight (pounds)	Machine size (inches)	Number of trucks per calender	Standard loads (pounds)	Time of heating per load (hours)	Calender production per hour (pounds)
		17 × 28	3	275	2.75	254
	(13)[1]	19 × 24	3	300	3.00	278
Bonds 1 and 2	30.0[2]	22 × 34	3	305	3.25	281
	34.8[3]	24 × 38	3	310	3.50	288
		28 × 34	3	335	3.75	309
		29 × 37	3	395	3.75	363
		17 × 28	3	355	2.75	330
	(16)[1]	19 × 24	3	400	3.00	372
Bonds 1 and 2	37.0[2]	22 × 34	3	430	3.25	397
	42.8[3]	24 × 38	3	415	3.50	383
		28 × 34	3	495	3.75	458
		29 × 37	3	435	3.75	405
		17 × 28	2	420	2.25	390
	(20)[1]	19 × 24	3	460	2.50	427
Bonds 1 and 2	46.2[2]	22 × 34	3	590	2.75	546
	53.5[3]	24 × 38	3	570	3.00	529
		28 × 34	3	650	3.25	602
		29 × 37	3	650	3.25	602
		17 × 28	2	275	2.25	254
	(13)[1]	19 × 24	3	300	2.50	277
Bond No. 3	30.0[2]	22 × 34	3	305	2.75	281
	34.8[3]	24 × 38	3	310	3.00	288
		28 × 34	3	335	3.25	309
		29 × 37	3	395	3.25	363
		17 × 28	2	355	2.25	330
	(16)[1]	19 × 24	3	400	2.50	372
Bond No. 3	37.0[2]	22 × 34	3	430	2.75	397
	42.8[3]	24 × 38	3	415	3.00	383
		28 × 34	3	495	3.25	458
		29 × 37	3	435	3.25	405
		17 × 28	2	420	2.00	390
	(20)[1]	19 × 24	2	460	2.00	427
Bond No. 3	46.2[2]	22 × 34	2	590	2.25	546
	53.5[3]	24 × 38	3	575	2.50	529
		28 × 34	3	650	2.75	602
		29 × 37	3	650	2.75	602
		17 × 28	1	690	1.50	461
	(24)[1]	19 × 24	1	700	1.50	474
Ledgers	55.4[2]	22 × 34	2	690	1.75	637
	64.2[3]	24 × 38	?	650	2.00	602
		28 × 34	2	775	2.25	719
		29 × 37	2	735	2.25	680

[1] Substance number. [2] Basis weight. [3] Standard ream weight.

increases over 40 in. Paper rolls are sometimes used to impart a very high finish; but they are not so commonly employed as cotton rolls, largely because cotton rolls are more resilient, and



(a) FIG. 14. (b)

touch the low spots in the paper without the use of extreme pressures. This results in a smooth, bulky sheet, with no tendency to high glaze.

The pressure is applied by means of hand screws *S*, Fig. 14 (*a*), which act on the top roll journals. The screws are turned either by a bar that passes through the head of a screw or by a large hand wheel keyed to the end of a screw.

47. Operation of Sheet Calenders.—The paper is first placed on a table *B*, Fig. 14(*a*), on one side of the machine. The sheets are fed through the calender by an arrangement of guiding tapes, the operator pushing each individual sheet between the band rolls *C*. These rolls and tapes automatically carry the paper through the calender rolls, and they deliver it onto the lay-off box or table *T*, Fig. 14 (*b*). The paper is fed first between the top rolls, and it is delivered between the bottom rolls. Against the two lower rolls, several bronze fingers are fixed, which act in the same manner as the doctor on the paper machine; they take the paper off the bottom roll and guide it into the lay-off box.

Usually a steam drum is fitted to the calender for blowing steam on the paper coming from the bottom roll, in order to take the static charge from the paper and enable it to be handled easily in the lay-off boxes.

The drive is usually by group belt or direct motor; the latter is the customary modern practice, since it saves power and allows a variation of speed, which the group-belt drive does not give.

The average horsepower required for a speed varying from 400 to 450 ft. per min. is: for a 28-in. stack, 15 hp.; for a 36-in. stack, 18-hp.; for a 42-in. stack, 20 hp. It is to be noted that sheet calendering decreases the bursting strength of paper about 2.5%, and decreases the strength of tear about 10%.

48. Paper Supply to Machine.—The operator is kept supplied with paper in such quantities that it can all be calendered before its temperature drops more than 10°F. The proper rate of furnishing the paper must be determined by experiment; and it will vary with the kind of paper and the speed of the machine. The quantity usually furnished is a pile of paper about 24 inches high. It is important that the paper not be brought out of the ovens or heating room until the calender is ready to use it; because, if the paper be left lying around, the entire operation of conditioning is wasted. Two operators are usually required, one to feed the paper and the other to catch it.

49. Production.—Many factors affect calender production, the chief of these being the skill of the operator in threading in the paper. The speed of threading in and catching is affected by the condition of the paper, since paper that has not been properly jogged, or which has turned-in corners or sticks along the edge, can be handled only with difficulty, thus slowing down the operator and increasing the broke.

50. Sheet-Calender Broke.—Sheet-calender broke consists mainly of turned-in corners and wrinkles that are due to bad jogging and incorrect conditioning. The personal equation of the operator enters largely into the matter of broke production; since, if the catcher be skilled, he can keep the percentage of broke lower, especially in the case of paper that has been rendered difficult to catch on account of faults in conditioning.

Very often much broke or rejection in sorting can be traced to the condition of the cotton rolls in the sheet calender. Proper alinement and constant attention to the surface of the cotton rolls will appreciably decrease the broke.

51. The Breaker.—The **breaker** is a special calender; it consists of two chilled-iron rolls, between which the paper is fed in the same manner as that employed in the case of the sheet calender. These rolls merely smooth out the paper somewhat; they do not give it a gloss. Much of the cockle given to the paper by loft drying is left in it after passing through the breaker. This machine is used chiefly on bond papers.

SHEET-CALENDERING BONDS AND LEDGERS

Size	Time	Size	Time	Size	Time
17 × 22 — 13	3.55	19 × 24 — 16	3.60	24 × 38 — 32	3.47
17 × 22 — 16	2.52	19 × 24 — 19.5	2.69	24 × 38 — 39	2.61
17 × 22 — 20	1.83	19 × 24 — 24.5	2.34	24 × 38 — 49	1.89
17 × 22 — 24	1.57	19 × 24 — 29.5	1.99	24 × 38 — 59	1.66
17 × 22 — 28	1.40	19 × 24 — 34	1.76	24 × 38 — 68	1.55
17 × 28 — 16.5	3.93	22 × 34 — 26	3.55	28 × 34 — 33	3.24
17 × 28 — 20.5	3.05	22 × 34 — 32	2.52	28 × 34 — 41	2.18
17 × 28 — 25.5	2.56	22 × 34 — 40	1.83	28 × 34 — 51	1.66
17 × 28 — 30.5	2.17	22 × 34 — 48	1.57	28 × 34 — 61	1.39
17 × 28 — 35.5	1.90	22 × 34 — 56	1.40	28 × 34 — 71	1.26

52. Time Allowed for Sheet Calendering.—The table on p. 32 gives the time allowance in hours and decimals of an hour, by a mill making bonds and ledgers, for sheet-calendering 1000 pounds of paper; the number following the dash is the weight of a ream of 500 sheets of the size stated.

PLATING PAPER

LINEN FINISH

53. Varieties of Finishes by Plating.—**Plating paper** is the process of producing special finishes by subjecting the sheet to

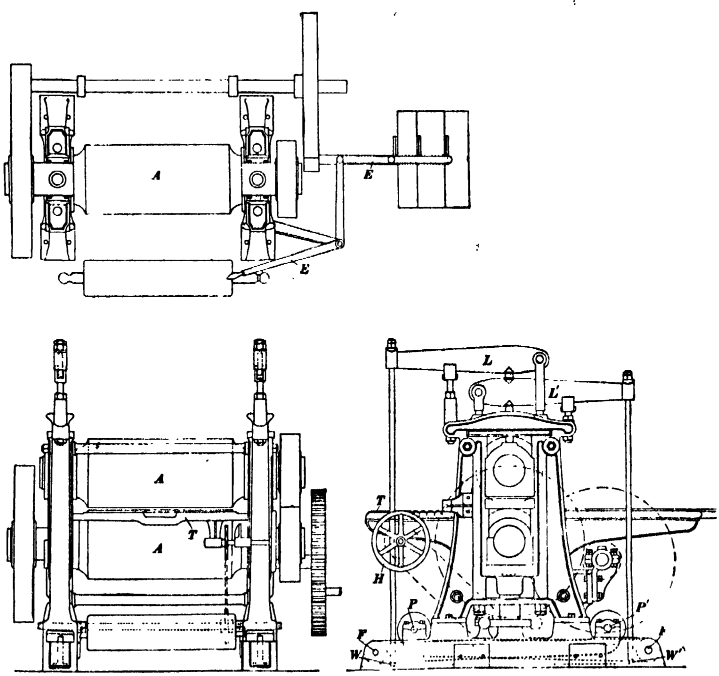


FIG. 15.

pressure while it is in contact with some material different from the sheet itself, and thus getting on the paper an impression that is characteristic of the material. Many varieties of finishes are thus made, the most widely used being the **linen finish**, which is obtained by making an impression of a sheet of linen on the

paper. Other finishes obtained are cardboard, burlap, crash, paper, lawn, antique, suede, ripple, wave, vellum, and plate.

54. The Plating Machine.—The plater, see Fig. 15, consists of two chilled-iron rolls A, about 17 inches in diameter, between which the *form* (see Art. 55) passes, forward and back, as the rolls reverse direction of turning. Pressure is exerted on the top roll by means of a system of levers L, L' and weights P, P'. The bottom roll is adjustable, the space between the two rolls being varied by moving the bottom roll either by means of a

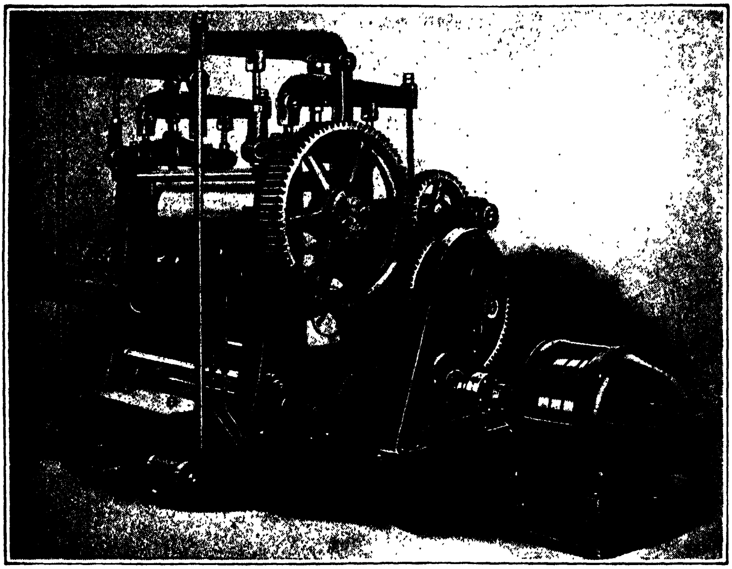


FIG. 16.

hand wheel H, which is geared to a screw that raises or lowers the roll, or by a power-driven device that is operated by a hand or foot lever. Fig. 16 shows a plater driven by a reversible motor.

The form, on going between the rolls, lifts the top roll, and the weights exert against this lift a pressure of between 60 and 80 tons. The pressure can be varied by adjusting the nuts on the top of the rods that connect the top and bottom levers, the greatest pressure being exerted when the top lever is horizontal. The pressure can also be varied by altering the weights. The width of the face of the rolls is from 33 in. to 44 in. The narrow

width generally gives a pressure of about 68 tons, and the wider plater gives a pressure of about 78 tons; but the pressure per inch of face is less in the latter plater. Faces are made as wide as 48 in., but these are not usually very satisfactory, since the forms are very heavy, and the finish does not seem to run uniform throughout the forms.

Platers are driven either by belts (using a crossed and open belt and belt shifter *E*, Fig. 15) or by special direct-connected reversing motors, Fig. 16. With the belt drive, it is not practical to run the rolls (17 in. in diameter) over 15 r.p.m.; but with the direct-connected reversing motors, the roll can be driven 17 r.p.m. It is claimed that production can be greatly increased by using direct-connected motors, and there is also a saving of power and of belts when some of the platers are not in use. Generally, a 15-hp. reversible motor is used, the power consumption being from 12 to 15 hp.

55. The Form, or Book.—Generally, a number of sheets of paper are laid, together with sheets of the material whose impression is desired, in a **book** or **form,** which is then run under heavy pressure between the two iron rolls of the plater. The form is usually built up with a number of zinc or iron plates, which serve to make the impression more definite and give the form stability. The usual form for linen finish is built up as follows: first, a zinc or iron sheet, then a linen sheet, then a sheet of paper, and so on until there are 8 sheets of paper and 9 linens, when a sheet of zinc or iron is laid on top; this quantity is called a **section,** and 10 sections make up a form, which contains, therefore, 80 sheets of paper. Sometimes, forms contain as many as 99 sheets of paper, being made up of 11 sections of 9 sheets each. The size of the form is limited by the weight that the platermen can handle most advantageously, the quality of the finish, and the liability of the top and bottom sections of a thick form to drawing (slipping) and leaving an unplated edge on these sections.

The make-up of the form varies greatly in different mills and in different parts of the country; this is due to the type of plater used, whether the operators are on day or piece work, and whether the mills are makers of paper or converters of paper. On the oldest type of platers, the top roll is driven, direct from the bottom roll, through a pair of spur gears on the ends of the rolls.

These gears have teeth of special shape, permitting a range of about $\frac{3}{4}$ in. in the opening between the rolls, with a maximum space slightly in excess of 2 in. On platers with the divided drive, in which the top roll and bottom roll are driven independently, the range of opening is 2 in., with a maximum of $3\frac{1}{2}$ in.; on some of the heavy machines, the opening is $4\frac{1}{2}$ in.

When operators are on piece work, there is always a tendency to run thicker books than when similar work is being handled by day operators. As a general rule, manufacturers classed as paper converters run thicker books than the paper mills themselves. In making up the forms, the so-called fabric finishes range from 50 sheets to 300 sheets of paper in a book, depending on the grade of paper and the finishing medium.

56. Two Methods of Building Up Forms.—Forms are built up and taken down in two different ways; the first way uses three operators, and the second way uses two.

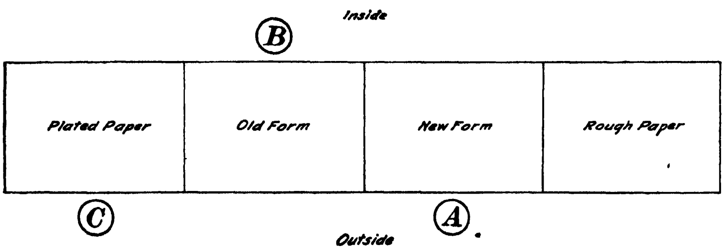


FIG. 17.

FIRST METHOD.—The three operators (usually, girls) may be designated by the letters A, B, and C; and they are seated at a table as indicated in Fig. 17. The form that has just been plated is placed in front of B, and is to be taken down. The new paper, which is to be made into forms and plated is placed on the right of A. B takes the zinc (or iron) off the form, puts it in front of A, and places a linen on the zinc; A puts a new sheet of paper on the linen while C is taking the plated paper off the old form and placing it in front of her. This process is continued until the old form in front of B is entirely taken down and a new form has been built up in front of A. The finished paper in front of C is taken away, the form in front of A is plated, and the entire process is then repeated. The tables are so made that the new form can be built up square, and the plated paper can also be

built up similarly. This method is appropriate for large sheets and in training green operators.

Second Method.—In the second method, the two operators sit as indicated in Fig. 18. *A* takes the zincs and linens from her right side and the new paper from her left side, and builds up the form in front of her; at the same time, *B* takes out the plated paper from the old form and piles it up in front of her.

Regardless of which method of building up forms is used, the operators change positions at intervals, since each operation demands a different degree of labor, and the change distributes the hard work more uniformly.

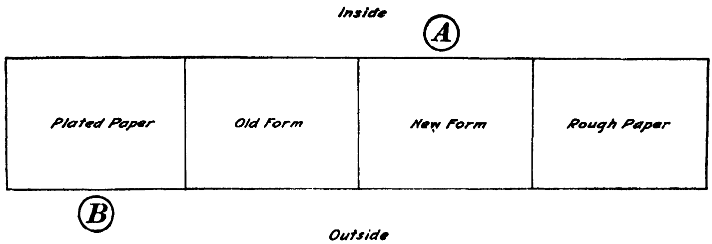


Fig. 18.

57. Comparing the Two Methods.—It has been found in practice that by using one method for one type of form and the other for a different type of form, greater production can be secured; also, that to get the best results, neither method should be used all the time. With the form built up as described in Art. **55,** with 8 or 9 sheets of paper between zincs (or irons), the first method, with three operators, is claimed to produce more; but, in the case of lawn finish, where the form is made up of from 35 to 40 sections, each consisting of zinc, linen, paper, linen, zinc, the second method, with two operators, is claimed to produce more. The two-operator method seems to work well with piece work.

Which of the two methods to use, or when to use one and when the other, are matters to be determined by experiment and careful time study. So many factors enter into the final result, such as finish, weights, and the abilities of the plater crew, that no definite rule can be laid down. The greatest production is secured by keeping the platermen continuously busy; and this means that the operators who are engaged in building up and taking down the

forms must also be working at their highest efficiency. In order to get this result, the work must be so evenly balanced that the operators produce just enough forms to keep the platermen working at capacity—and only just enough—because, if they produce more than the platermen can take care of, some operators will be kept waiting for their forms to be plated. It is necessary, therefore, that many time studies be made, to record the relative speeds of the operators, and to note the effects secured with various types of machines and through different methods of handling.

In the case of the three-operator method, the absence from the table for a short time of one operator does not stop the building of the form, as the two remaining operators can still carry on; but in the case of the two-operator method, the absence of one operator entirely stops work on that form.

58. A Practical Example.—The following example shows the increase in production that was obtained through studies made in one mill that was plating lawn-finish paper. Originally, the form consisted of 30 sheets, the plater crew being composed of one man and 4 groups of 3 operators each, a total of 13. With the crew thus composed, it was found that the platerman could not keep up with the operators. The form was then increased to 40 sheets, which took a longer time to build up and take down; and it was thought that this would balance production. But it was found that the heavier form handicapped the platerman to such an extent that he still could not keep up with the operators. Eventually, by making the crew consist of 2 platermen and 5 sets of 2 operators each, a total of 12, and by using a 40-sheet form, the production was increased 20 per cent.

59. Number of Laborers Required.—The crew for a plating operation for the three-operator method, generally consists of 4 groups of 3 each and 1 platerman; and for the two-operator method, of 5 groups of 2 each, a spare operator, and 1 platerman, though 2 platermen are sometimes used. Most mills vary these methods somewhat, since the quality of paper produced and the class of labor employed have a great bearing on the most effective methods of obtaining the best results.

60. Operation of Plating.—The platerman slides the form off the table on which it has been built up and onto a movable or

swinging carrier, provided with rollers. The form is now brought to the plater, either by being pushed along on the carrier or by having the table moved. The form is pushed from its conveyor onto the plating-machine table T, Fig. 15, which is also fitted with rollers in order to make the form travel more easily. The form is then pushed between the two iron rolls, which draw it through, when the operator (platerman) reverses the machine, bringing the form back in front of him. He then turns the form end for end, and puts it through the machine and back again, making four times in all that the form has gone through the rolls. The plated form is now pushed along on the carrier to the group of operators that has a form ready to plate, and this finished (plated) form is exchanged for the new form just built up for plating. The plated form is taken down, the zincs and linens in it going to make up a new form.

Broke due to plating is generally caused by careless handling; that is, by not building up the form square, or through spoiling the paper by tearing it or making it dirty. Bad linens also cause broken-paper broke. This broke is largely sorted out by the plater girls.

The operators are kept supplied with rough (new) paper, and the finished (plated) paper is taken off their tables by a man whose duty is to attend to this. To keep a plater working efficiently, no operator must ever be kept waiting for paper.

61. Static Charge.—When going through the plater, the form sometimes gets charged with static electricity. This trouble usually occurs in the cold, dry days of winter; and it may also occur if the paper is made too dry on the paper machine and not properly tempered. The best preventive is to have the paper sufficiently moist, and to have some humidifying apparatus for keeping the air damp. Paper charged with electricity is very difficult to handle, because the paper then sticks to the linen and a great deal of broke is made. Another remedy is an apparatus that neutralizes the static charge by using an alternating current, which is distributed to the charged paper by means of a bar, called an **inductor**, placed over the paper.

62. Moisture Content and Power Consumption.—In order to get a clean-cut linen finish, and the desired surface polish, it is necessary that the paper contain about 7% to 7½% of moisture; for lawn finish, about 6% of moisture is best.

The horsepower required to drive a plating machine is from 12 hp. to 15 hp.

63. Time Consumed in Plating.—The following table gives the times in hours and decimals of an hour that are allowed for 3 operators to plate 1000 pounds of lawn or linen finish paper.

Size	Linen	Lawn	Size	Linen
21 × 33—34.0	....	19.30	18 × 23—32.0	14.20
21 × 33—44.5	7.03	16.00	18 × 23—26.5	11.80
21 × 33—52.0	6.00	13.71	18 × 23—31.0	10.08
21 × 33—59.5	5.25	11.98	21 × 24—27.0	11.55
22 × 34—40.0	7.80	17.83	21 × 24—32.5	9.63
22 × 34—48.0	6.51	14.85	21 × 24—38.0	8.23
22 × 34—56.0	5.58	12.75	21 × 33—37.0	8.44
22 × 34—64.0	4.88	11.14		

64. Life of a Linen.—The life of a linen is variable; a linen seldom wears out, but is spoiled in nearly all cases by being cut with the irons (or zincs) in the forms, or it is torn at the edges. The linen is then cut down to a smaller size; and it continues to be cut down until it is too small for further use.

The stiffness of a pasted linen has a great bearing on its life, as a stiff linen is more liable to crack and to be cut at the edges. But since a stiff linen is easier to handle when building up a form, the disadvantage just mentioned is somewhat offset. The happy mean is to get the linen as flexible as ease of handling will permit.

Many factors affect the life of a linen, the chief one being the quality of the paper to be produced, since a linen may be run in a much worse condition on a low grade of paper than on a high-class paper. The number of times a linen can be cut down depends on the variety of small sizes of paper to be plated on which it can be used. The care exercised in building up a form affects the life of a linen, since a form that is not built up square is inclined to cut the linen at the edges. Putting the form through the plater diagonally also throws the form out of square.

Two linens are usually pasted together when they are to be used for regular finish; single linens are used for lawn finish, which requires a finer texture of linen in order to get the best results.

OTHER FINISHES AND SPECIAL MACHINES

65. Cardboard Finish.—This finish is obtained by using cardboards instead of linens, and the result is a very high finish. The form is built up of 7 sections, 10 sheets of paper and 11 cardboards to each section, and 8 irons, one on either side of each section.

66. Burlap Finish; Ripple Finish.—The **burlap finish** is secured by placing a sheet of burlap between two sheets of cotton, and using this in a form that is built up in sections that consist of iron, burlap, 5 sheets of linen and 4 of paper alternately, burlap, and iron.

The **ripple finish** is produced by placing a sheet of paper between two plates, the surfaces of which have a ripple formation. These plates are made from paper that has been given this peculiar lumpy formation on the paper machine, by running the machine with no shake on the wire and no dandy roll. Or, in some cases, it is made by placing the paper between two sheets of pulp, which have been made with the correct formation to give the type of ripple desired. Ripple-finish paper is very often made with a more or less ripple formation on the paper machine, and it is then finished with ripple plates; this gives a more pronounced ripple effect, as both the *look-through* and the surface effects are secured. The form is built up in a manner similar to that used for other finishes.

67. Plaid-Paper Finish.—This finish is obtained by pasting strips of paper between two sheets of cotton, using it in the same manner as in the case of burlap finish. Many other variations can be obtained by pasting thread between the cotton sheets, so as to form any desired pattern of straight lines or checkered designs.

68. Water Finish.—Water finish is usually done on the calender stack of the paper machine. As the web of the paper passes through the calender, it is moistened on either one or both sides by a fine spray of water, or by troughs or boxes that supply a film of water to one or more calender rolls. The surface thus softened takes a very high finish. Too much water may blacken the paper. Reference may be made to the Section on *Paper Coloring*, Vol. IV, where a calender stack fitted for calender coloring is shown.

CAPACITY OF EMBOSSERS

Speed	Roll width	Average weight	Basis wt. 27 lb.		Basis wt. 30 lb.		Basis wt. 35 lb.		Basis wt. 40 lb.		Basis wt. 50 lb.		Basis wt. 100 lb.	
Ft./min.	Inches	Pounds	Hr./roll	Lb./hr.	Hr./roll	Lb./hr.	Hr./roll	Lb./hr.	Hr./roll	Lb./hr.	Hr./roll	Lb./hr.	Hr./roll	Lb./hr.
68	25	345	4.34	80	3.90	88	3.34	103	2.92	118	2.34	147	1.17	294
	32	440	4.34	101	3.90	113	3.34	131	2.92	151	2.34	188	1.17	376
	37	510	4.34	118	3.90	131	3.34	153	2.92	175	2.34	217	1.17	434
	40	550	4.34	127	3.90	141	3.34	168	2.92	188	2.34	235	1.17	470
102	25	345	2.89	119	2.60	133	2.23	155	1.95	177	1.56	221	0.78	442
	32	440	2.89	152	2.60	169	2.23	197	1.95	225	1.56	282	0.78	564
	37	510	2.89	176	2.60	196	2.23	229	1.95	262	1.56	327	0.78	654
	40	550	2.89	190	2.60	211	2.23	247	1.95	282	1.56	353	0.78	706
134	25	345	2.20	156	1.98	174	1.70	203	1.48	233	1.19	290	0.595	580
	32	440	2.20	200	1.98	222	1.70	259	1.48	297	1.19	370	0.595	740
	37	510	2.20	232	1.98	257	1.70	300	1.48	345	1.19	429	0.595	858
	40	550	2.20	250	1.98	278	1.70	324	1.48	372	1.19	462	0.595	924
200	25	345	1.47	235	1.33	260	1.14	303	0.99	348	0.795	434	0.398	868
	32	440	1.47	300	1.33	331	1.14	386	0.99	444	0.795	553	0.398	1106
	37	510	1.47	347	1.33	383	1.14	447	0.99	515	0.795	642	0.398	1284
	40	550	1.47	374	1.33	414	1.14	482	0.99	556	0.795	692	0.398	1384

A separate moistening machine is used for glassine papers. About 20 per cent of moisture, by weight, is put into the sheet, and the paper is allowed to stay in the roll for some time before running it through the supercalender. The supercalender used is extremely special, with a number of steam-heated rolls, relatively large drying capacity, and provisions for draws from all the nips. Sweat rolls and brush sprays are often used to moisten the dull side of machine-glazed paper, previous to running it through a supercalender, for the purpose of putting a finish on the dull side equal to the machine glaze on the other side.

69. Embossing Machine.—Much paper that was formerly plated is now embossed, and many new surface designs are possible. The **embossing machine** consists of metal rolls, the surfaces of which have been engraved with any design or pattern that is desired. Metal rolls must be in pairs, male and female. Sometimes a paper or cotton roll is used to receive the design or pattern of a steel-engraved roll instead of using two steel rolls. The paper is fed off a reel and through the nip of the paper and steel rolls, or the two steel rolls; and when the pressure is applied by forcing the metal roll against the paper or the other steel roll, the marking on the metal roll is impressed on the paper.

The paper to be embossed should be cold and have an even moisture content. For instance, 100-per cent sulphite papers seem to take the impression better with a moisture content between $5\frac{1}{2}$ and 6 per cent; rag-content papers should have between 4 and $5\frac{1}{2}$ per cent moisture; kraft papers should have a slightly higher moisture content than 100-per cent sulphite papers. Failure to prepare paper properly before it is embossed reduces the production and lowers the quality of the design.

The horsepower requirements for a typical embossing machine 40 in. wide are 2.5, 3.75, 5.0, and 7.5 hp. at speeds of 68, 102, 138, and 200 ft. per min., respectively. The table on p. 42 gives representative figures for embossing 100-per cent sulphite paper.

FINAL FINISHING OPERATIONS

PASTING OPERATIONS

70. Purpose of Pasting.—The **pasting process** is used for pasting together two or more sheets of paper, pasting paper to

containers or cardboard, and pasting coated or offset paper to blotting paper. The uses to which pasted stock is put are very numerous; all the better classes of cards are made of pasted stock, several thicknesses of paper being considerably stronger than a single-sheet card of the same thickness. Cardboard containers nearly always have paper (called **liners**) pasted on one or both sides, as it greatly improves the appearance, and enables printed matter to be put on more easily. The liner is put on some boards in the course of its manufacture on multicylinder machines.

71. Pasting Machines.—Pasting machines are divided into two classes: in one class, the machine pastes paper off the roll or in the web; in the other class, it pastes the paper in sheets. In the **roll machine,** the paper or boards to be pasted are fed off different reels, the center sheet going through the paste trough and between the paste rolls, which distribute the paste evenly. The paper is then combined with the other two sheets by passing through *squeeze rolls,* and is dried by being passed over a series of drying cylinders. At the end of the machine is a cutter, which cuts the pasted paper into sheets of the required size.

There are several methods of applying paste, which differ with the machine. One method is to have the top and second sheet go over separate paste rolls, and then go through a press with a third sheet, which sticks to them.

72. Lining Sheets.—When sheets of straw or boxboard are lined with paper, the sheets of board are placed on an endless felt, about ½ in. apart, and are kept in position by an endless rubber deckle strap. A roll of lining paper is placed on an overhead frame; the paper, after passing over a pair of paste rolls, joins the sheets of board and passes through a pair of squeeze rolls. The pasted paper and board is carried over dryer cylinders, by endless felts, to the break rolls, which separate the sheet by tearing the lining paper.

73. Sheet Pasting.—In the sheet-pasting machine, the sheets are fed by hand through the paste rolls, and are carried to the *laying-off table* on a series of endless strings: here they are smoothed out and piled accurately. In the case of the *two-ply sheet,* the first sheet fed through the rolls gets pasted on both sides; after this sheet is through, the sheets are fed through the

rolls in pairs, the bottom sheet of the pair sticking to the top sheet on the pile, and the top sheet rests on the pile, paste upward, waiting for the bottom sheet of the next pair. With *three-ply sheets*, one sheet is fed through, then two sheets, and so on alternately, the single sheet sticking to the top sheet on the pile and resting on the pile, paste upward, waiting for the bottom sheet of the next pair, which is followed by a single sheet again and by another pair; this causes three sheets to stick together, and leaves one sheet free. By feeding two single sheets after each pair, a *four-ply sheet* is obtained.

74. Broke in Pasting.—The sheet-pasting machine does not cause much machine broke, nearly all the broke in the pasting process being due to the many times the paper is handled; consequently, a great saving in the amount of broke made can be effected by exercising care when transferring the paper from one operation to the next. When drying pasted sheets, broke may result through lack of accurate clipping of the paper in the hangers, where it tends to fall down on drying out: this may be overcome by employing corrugated clips, which give a firm grip on the paper.

75. Paste.—Many kinds of paste are used in this process; for instance, starch and water, and silicate. In making paste with starch, stir up starch with cold water to a smooth cream consistency, and then bring it to boil. The boiling is effected by using either live steam or a series of steam coils; the latter makes the best paste, but it takes considerably longer to cook. Boiling is continued until a perfectly smooth paste is obtained. A poor paste causes undue losses, because of the ineffective laminating of the sheets.

TRIMMING THE SHEETS

76. The Trimming Machine.—The **paper trimmer** (cutter), Fig. 19, is used for squaring piles of paper (making all four corners square), trimming off rough edges, and also for dividing piles of large-size sheets into smaller sizes as required. The trimming of books, pamphlets, tablets, and other printed matter can be done on this type of machine.

The trimmer shown in Fig. 19 is an overcut machine, the knife moving downward through the paper, and the essential features

are: the knife K, which cuts with a vertical shear motion; the table T, upon which the pile of paper is cut; the cutting stick and back gauge G; the oblique guide M; the starting lever L; starting bar B; and gauge H, which controls the pressure of the clamp C on the paper.

The paper trimmer has developed from the primitive type, wherein the paper was held down by hand and the knife drawn through by hand, into the modern automatic type, now in almost universal use. The evolution has been rapid and distinctly marked in the essential features.

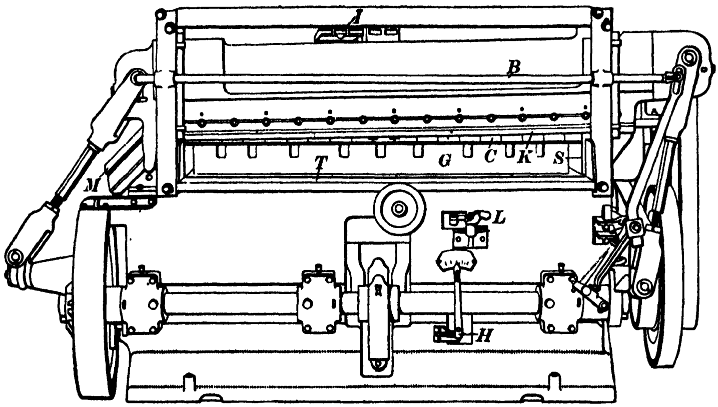


FIG. 19.

The *modern cutter* is designed with the knife operated by cranks, which give an endwise motion to the knife; with quick and accurate adjustments for the knife; with a foot treadle for bringing the clamp down to the pile when it is desired to see where the knife will strike; with an accurate dependable device for moving the back gauge and the pile, and measuring quickly the widths to be cut; with powerful clamping pressure, automatic for all-height piles and instantly adjustable for heavy or delicate work.

The knife cuts through the pile of paper with a double-shear motion, the right-hand side of the knife being higher at the beginning of the stroke, but the whole knife edge being parallel to the table when the cut is completed. The upward stroke returns the knife to its original position. A cutting stick is set in a slot in the table, thus preventing the knife from coming into contact with the iron table. This stick is made of hardwood; it

is usually $\frac{3}{4}$ in. square and as long as the knife blade. The stick may be used on all four sides if properly and correctly inserted in the slot.

Trimmers are made in sizes ranging from 16 in. to 94 in. in width. The smaller sizes are used for small work and the more simple cutting operations, while the larger sizes, known as *mill cutters*, are used where heavy work and large production are required. The larger machines are equipped with power-driven gauges for moving material toward the knife. The cutting is accurately measured by a graduated band and hand wheel, conveniently located for the operator.

77. Speed of Cutter.—The speed of the automatic clamp cutter is very rapid: production possibilities are very large. However, much depends on the skill of the operator in placing and removing the material from the machine, and also on the kind of material to be cut. Adequate clamp pressure properly distributed to the pile of paper, correctly dimensioned, properly ground and honed knives, as well as adequate clutch driving power, are essential to satisfactory operation.

A late development for the trimmer is a device to move the back gauge automatically. This device has an electric carriage synchronized with the back gauge; it introduces accuracy and speed, and eliminates the perpetual reading of the tape by the operator. Electric stops are set in correct position, and each stop is signaled by a light in front of the operator. The pile of paper is moved forward automatically, once the stops are set in the desired positions.

78. Cutter Knives.—The knife is most important. It must be sharp; it must be of proper shape and thickness, of correct bevel, of proper temper, and be free from burrs or high spots on the back face. A knife that is defective in any way will invariably cause inaccurate cutting. In most cases, the 5-inch width cutting knife is ground with a 26° bevel. Very hard materials sometimes require a knife having a bevel greater than 26°, while softer materials require a knife of less than 26° bevel.

79. Types of Drive and Power Required.—Four types of drive may be used on paper trimmers: (1) belt drive; (2) chain drive; (3) direct gearing; (4) direct-connected electric motor. Each method has its merits, and opinion differs as to

which is best. The driving method must be decided by the nature of the work to be done and by local conditions. The horsepower required to drive a trimmer varies according to the size of the machine and the density of the material to be cut.

80. Safety Devices.—The most important safety device is a careful workman: the careless workman cannot be protected by any safety device ever invented. At least four safety devices should be installed on every trimmer: (1) automatic stop for the clutch; (2) automatic friction brake; (3) automatic counterpoise for holding the knife bar and clamp in top position; (4) automatic steel safety bolt to hold the large gear stationary until the starting handle is pulled.

81. Inspection.—Periodic inspection is an important part of safe operation, and is a factor for long life of the machine. All parts of the trimmer should be inspected at least once a week, and the places indicated on the oiling chart should be properly lubricated each morning before starting the machine.

82. Production.—It is practically impossible to lay down a schedule of production that would cover all classes of paper. The amount of paper trimmed is governed by the kind of paper, size of sheet furnished, size of sheet to be turned out, local operating conditions, and the skill of the operator. Two mills making the same grade of paper may operate under such different conditions that a comparison of tonnage is out of the question.

SORTING, COUNTING, AND SEALING

83. Sorting.—**Sorting** is necessary in order to pick out of the finished paper those sheets that are not up to standard. The degree of cleanliness required depends entirely on the price of the paper and the use to which it is going to be put. Many of the lower grades of paper are not sorted at all, and others are sorted on the cutter. Some papers are *overlooked;* that is, all sides of the ream are inspected to detect broken edges and any other flaws.

When sorting paper, each sheet is separately taken from the pile and examined, generally on both sides. Paper is usually sorted into either two boxes or three boxes. In the first case, *perfect paper* is placed in one box and the *broke* in the other box; in the second case, perfect paper goes into one box, *medium,* or

seconds, into another box, and the broke into the third box. The broke is usually returned to the beaters and remade into paper, although customers sometimes handle their own broke. The chief faults to be looked for are dirt, wrinkles, tears, holes, oil spots, broken or curly edges, and calender cuts, caused by the pressure of the calenders on wrinkles.

It is important that the operator be kept well supplied with paper, and that the sorted paper be removed when the order has been filled or the boxes are full. The tables should be of a comfortable height for an operator to work on; and it is important that good lighting be available at all times, since sorting under poor light is both inefficient and slow, and decreases production.

NOTE: It will be seen that sorting applies to paper in sheets. When defects occur in paper to be shipped in rolls, an effort is made to remove it during the rewinding. If this is not done, the customer will usually remove it and claim a rebate.

84. Counting.—Flat paper is nearly always sold by the thousand (1000) sheets or the ream of 500 sheets or 480 sheets; consequently, it is necessary to count the sheets accurately. Badly counted reams cause a great deal of trouble to the customer.

Paper is counted either in reams or half reams, according to the weight and size of the paper, and many methods are used in counting. Usually, the corner of the ream is turned back, the operator fanning out the edge. By using four fingers of the right hand and taking four sheets with each finger, 16 sheets are counted. This is done three times, making a total of 48 sheets. These are turned back, and the process is repeated 5 times, making a total of 240 sheets, or one-half a ream of 480 sheets. For a ream of 500 sheets, 10 more sheets must be counted off to make half a ream. The counted ream or half ream is picked up by the counter's helper and piled. It is best to count the sheets on the truck upon which the paper is brought to the counter, it being piled on the truck used to carry it away.

Sometimes the counting is done in the same operation as the sorting. The sorter, on placing a sheet into the *perfect* box, presses an indicator, which registers the number of sheets counted. In practice, this latter method is not always reliable, because it is difficult to train the sorter always to press the indicator; more attention must be given to the sorting than to the counting.

Many mills are equipped with counting devices on their layboy cutters; these will count the sheets and insert tags at half reams or reams. Counting done by this method is particularly accurate, although, of course, when the number of sheets being cut does not divide exactly into 500, there are a few sheets over or under. These counters are so arranged that if they count a few sheets over on one ream, they will count a certain number of sheets short on the following ream. For instance, if the cutter is cutting 7 reels of paper, the counter would record 504 ($= 7 \times 72$) sheets in the first ream and 497 ($= 7 \times 71$) sheets in the second ream. This method of counting is only used when the cutting operation is the last finishing operation, since any other finishing operation, such as sorting, would spoil the count.

85. Packing and Sealing.—Before shipment, most paper is sealed up in separate ream or half-ream packages, with gummed-paper tape, and is then marked with some descriptive label that shows the contents of the package. Usually, when the weight of the package exceeds 50 pounds, it is sealed in half-ream packages. The manner in which the labeling and sealing of the packages are done greatly adds to or detracts from the appearance of the finished packages. When the sealed reams are piled, all labels should be in a vertical column, one above the other, and all packages should be sealed in the same manner. Sometimes, when a stiff package is desired, pulp boards are put on the top and bottom before sealing.

The sealed packages are next cased, baled, or tied in bundles, or several reams are wrapped in thick paper. A charge is usually made to the customer for packing, the amount depending on the method used.

When paper is used without being sealed in separate reams, markers are used to divide consecutive reams, to show the division.

86. Cases, Bales, and Bundles.—It is most important that the case be so made that the paper will fit exactly; since if the case be not entirely filled with paper, trouble will be caused by the buckling of the paper inside the case.

In **baling,** the paper is covered with burlap, baled up under pressure, and is protected on opposite sides by boards; iron bands are passed around the bale, thus keeping it solid. For

domestic shipment, the burlap is often omitted; crates are used, top and bottom, and the whole is tied with light manila rope.

Flat wrapping papers and printing papers are wrapped in **bundles**. One ream is laid on the wrapping paper, a second ream is laid on the first in such a manner that the ends overlap it half way, the sides being flush; the free end of the first ream is then folded over to meet the end of the top ream, and the free end of the top ream is folded under to meet the end of the bottom ream. If the paper is light (thin), two reams may be used for each layer. In either case, after the ends have been folded, the wrapper is then folded up and tied with twine.

Much printing paper is now shipped on *skids*, low platforms holding up to a ton. Reams are marked; heavy wrapping is put over the whole, which is tightly strapped with steel bands. These skids are conveniently moved by lift trucks.

The cases, bales, bundles, or skids are stenciled and labeled with the size, weight, and character of the enclosed paper.

87. Weighing.—The cases or bales, with the contained paper, are weighed, so the exact shipping weight may be known. If an error has been made in regard to the number of reams packed, this weighing will generally reveal it, since the actual weight would then differ from the normal weight. The actual weight of the paper is found by subtracting the sum of the weights of the cases and truck from the total weight of cases, truck, and paper, weighed as a whole. The work of the shipping department in catching errors is especially important, as it is the last department to handle the paper before it leaves the mill; hence, a careful checking system in the shipping department is necessary. By means of such a system, errors are eliminated in the shipping room, and errors that are made in the other departments are nearly always caught.

OCCASIONAL FINISHING OPERATIONS

88. Folding.—The operation of **folding** is sometimes conducted in the paper mill; it is chiefly used when boxes of paper (stationery) are being put up and the writing paper is folded. The machine consists of a table, with an adjustable back gauge. Across the center of the table is a long slot, parallel to the back gauge; while directly above the slot, and parallel to it, is a blunt-

edged knife that moves rapidly up and down. The paper to be folded (usually six sheets at a time) is fed by hand under the knife, one edge of the paper touching the back gauge; as the knife descends, the paper is folded into the slot, being pressed in by the descending knife. The paper then falls into a jogging tray, from which it is removed and piled. The piles are put under a slight pressure, to make the folded edges more distinct. There are also several kinds of automatic folders on the market; these feed, fold, and collect automatically. Some paper is folded by hand.

89. Ruling the Paper.—Machines for ruling paper are of two types, the disk machine and the pen machine.

The **disk ruling machine** is operated by passing the paper off the reel and under revolving disks, which rule the lines. The disks take ink off an ink roll and transfer it to the paper. With this type of machine, only straight, continuous faint lines can be drawn. The machine can be run at high speed, and is chiefly used for ruling exercise books and writing paper. The paper, when fed in web form, is cut on the machine, just before going under the disks.

The **pen ruling machine** is operated by feeding sheets of paper along endless strings, under a series of pens that are set the required distance apart. The ink is fed to the pens by means of small wicks, dipped in ink and resting on the base of the pens. The pens are very narrow troughs, ground nearly to a point; they are mounted on a shaft that is controlled by an eccentric cam, which can be so set that the pens come into contact with the paper at any desired position. This enables **struck ruling** to be done; that is, lines that break at definite places, like the vertical lines of an account ledger, which touch the horizontal lines at the top of the page and end on the bottom line of the page. The sheets are automatically fed into this machine by means of fingers that work in conjunction with the pen mechanism, so that exact coordination is obtained between the sheet and the pen striking it. This is necessary in order that the pen shall strike the paper in the same relative spot every time. After being ruled, the paper is jogged automatically, at the end of the machine in the lay-off boxes. If desired, several colors of inks may be used.

Several variations of these machines are in use; one, the L machine, rules the faint lines on one side of the L, then carries the paper through an angle of 90° and rules the struck lines on the other side of the L. There are also several machines that rule the paper on both sides in the same operation.

Folding and ruling are operations that frequently are not performed by the manufacturer of paper; in such case, the folding and ruling is done by large stationers and by manufacturers of blank books.

PRODUCTION FACTORS

ATMOSPHERIC CONDITIONS AND STORAGE

90. Atmospheric Conditions.—Good light, both natural and artificial, is of the utmost importance in the finishing room; with poor light, it is impossible to get good production or good quality. The temperature of the room must also receive attention; about 65°F. is the best working temperature. As might be inferred from previous statements, the finishing room should be kept at constant humidity; this enables the paper to be handled more easily, and assists in turning out a standard product. A relative humidity of about 55% is considered ideal; this keeps the moisture content of the paper at about 6% to $6\frac{1}{2}$%.

91. Sample Department.—A sample department is generally located in the finishing room. This department passes on all paper, as to finish, color, dirt, strength, etc.; it keeps samples of every order that is filled, for purposes of reference in case of repeat orders or complaints.

92. Storehouse.—In mills where all orders are not shipped to customers immediately, the paper storehouse is a necessity. The storehouse should be dry and well lighted; it should be so divided (partitioned) that paper can be easily located and moved to or from any part of the building without undue labor. To achieve this result, each grade and size should be stored in the definite place that is set aside for it, and all aisles should be kept clean.

The best layout for a storehouse, so any grade or size of paper can be found readily, is to divide the storehouse into definite rectangular spaces, bounded by aisles and sub-aisles, each space

being marked plainly with some symbol to identify it. These spaces can be subdivided into sections, each being marked with the space symbol and with a section symbol. If necessary, the sections can also be subdivided into smaller units. Assuming such a system to have been installed, if it be desired to locate some paper that is recorded in the file as, say, *A B D*, it is quickly found by going to the space marked *A*, and then finding unit *D* in subdivision *B* of that space. It is absolutely essential that a good water-sprinkler system be installed in the storehouse.

FINISHING-ROOM LAYOUT AND TRANSPORTATION

93. Finishing-Room Layout.—The layout of the finishing room depends to a great extent on the amount of paper made and the different processes it must go through; but the general principles are the same in all cases. Restrictions of space prevent many mills from having their finishing rooms ideally situated. The main points for a good layout are the following:

a. All rooms should be situated in the same sequence as the order of the finishing operations, so that when the paper is being finished, it will always move in one direction.

b. There should be ample storage room for paper between operations; then if an operation be held up by a breakdown for a short time, the department's preceding do not get too congested, filling up the trucking aisles with paper.

c. Good floors and plenty of light and ventilation are also very necessary, to increase both production and quality of the work.

94. Transportation.—The term **transportation** here refers to the means for moving the paper from one department or point to another. The usual methods of transportation through the finishing room are by: (*a*) four-wheeled truck; (*b*) platform truck; (*c*) electric truck; (*d*) elevators and conveyors.

The use of the ordinary **four-wheeled truck** makes it necessary that the paper be kept piled, either on the truck or on the floor, while waiting for the next operation; this requires a lot of trucks, and it also necessitates a great deal of labor in piling the paper on a truck every time it is required to move it.

The **platform truck** obviates the difficulties just mentioned, the paper being piled on wood or steel platforms. To move the platform, a three-wheeled lifting truck is pushed under the

platform, which can then be hauled away and located where desired. One truck can, in this way, take care of a number of platforms.

When using the **electric truck,** electricity is substituted for hand power for hauling and lifting purposes; it is especially useful when very heavy weights are to be lifted, such as cases of paper that are being moved and piled. Electric power may also be used for hauling a long series of trucks, and specially designed trucks are used for handling rolls.

Electric elevators are generally used for moving paper from one floor to another; in some cases, **gravity conveyors** are used, generally from the shipping room to the cars when the paper is in cases or bales, or for unloading pulp laps or bales. Hand-operated elevators are likewise used for piling paper. Electric or compressed-air lifts, with overhead trolleys, are commonly used for moving full-width reels of paper from the paper machine.

95. Floors.—The main requirement in connection with the floor of a finishing room is a smooth, hard surface, producing no dust; this facilitates trucking, and it enables the floor to be cleaned easily. The condition of the trucking aisles has a great influence on production, since a bad floor slows down transportation, causes a great deal of unnecessary labor to the truckmen, and is often a source of accidents. One of the most satisfactory types of floor for hard wear is that in which iron gratings are sunk in concrete; this gives a smooth, hard surface, which is not liable to crack and wear in holes, which is frequently the case with unreinforced concrete floors. Hardwood, wood blocks, and wood floors covered with iron plates are also used. The use of bituminous floor coverings is coming into considerable favor. The hardness can be adjusted; the floor does not crumble, and it is free from dust.

96. Broke.—General finishing-room broke is mainly caused by the carelessness of the operators, who can do a great deal to cut down this waste by observing a few simple rules, such as not writing on the top of loads, not handling paper with dirty hands, not walking on paper, not upsetting loads. Considerable broke is caused by walking over the paper, or wiping the hands on paper, and then putting the paper into the broke box instead of into the box for waste paper. This causes dirty paper to be

pulped up again; and when it is made into paper, a large quantity is spoiled by the inclusion of this dirt.

97. Total Broke for All Grades.—The following table shows the totals (in per cents) of broke allowed in finishing various grades of paper. These totals include all processes undergone after leaving the paper machine.

Grade	Per Cent
Machine finish	7½
Sheet-calender finish	8
Lawn finish	8½
Breaker finish	9
Linen finish	8
Supercalender finish	7¾

98. Total Broke for Different Departments.—The following table gives the per cents of broke allowed to the various departments.

Department	Per Cent
Cutters	2
Platers	½
Sheet calenders	1½
Trimmers	5
Supercalenders	¾
Ruling	2
Pasting	3
Sorting (plated paper)	3
Sorting (sheet-calendered paper)	5

FINISHING AND PACKING COARSE PAPERS

99. Finishing.—Up to this point, the treatment of the subject has been restricted mainly to fine papers and book papers. The finishing of the so-called coarse papers is usually done on the paper machine. Fourdrinier and cylinder machines produce a paper with a calender finish on both sides, called M.F. (machine finish); Yankee machines produce a paper highly polished on one side, called M.G. (machine glazed). The principal exceptions are: crepe papers, which are made in one operation and are finished in another operation, though the two operations are combined on some machines and on some grades; and leather boards, etc., which are made on a wet machine, dried in single sheets, and are finished in a breaker calender. Other boards are finished on the paper machine.

Wrapping papers are sometimes given a very smooth finish by so arranging a distributing trough that water lies in a nip, near the top, on each side of the machine calenders. This softens the surface of the paper, and the following rolls glaze it. In another arrangement, the spray device, the water is atomized, sprayed over the paper, and the finish is controlled by the amount of water used. The surface of the paper may be softened slightly by means of a 'sweat' roll. This may be the last dryer, run without steam, or a roll in which cold water circulates.

Newsprint, wallpaper, and some book papers are also finished on the paper machine.

100. Newsprint.—There are two regular grades of newsprint, **standard news** and **halftone news.** The former is that generally used; it contains 80% to 90% groundwood, the remainder being sulphite pulp. Halftone news may contain more sulphite, some soda pulp or de-inked papers, a little clay, and some coloring material to produce a white sheet. Standard news will pass through five to seven nips of the calender on the paper machine; while halftone news is frequently supercalendered in addition. The paper is slit and rewound on the paper machine, as usual; and, if sold by the ream, it is cut on the rotary cutter.

101. Packing Coarse Papers.—Coarse papers, and some printing papers, are packed in bundles (see Art. **86**) or rolls.

Tissue paper is wrapped in reams of 480 sheets, except copying tissue, which is 500 sheets to the ream, and 10 reams are put up in a bundle. The finish is usually plain machine finish, M.F., or machine glazed, M.G. Cutting may be done as described in Arts. **12–26,** or by using the expansion reel, described in *Paper-making Machines,* and then trimming to the correct size. The reel counts the sheets.

Wrappings may be packed flat or folded, as well as lapped; a ream contains 480 sheets.

In the case of boards, the sheets are cut on a cutter on the machine. The cheap grades, such as wood board, etc., are put up in 50-lb. bundles, which are tied with four strings, and cards are used to keep the strings from cutting the edges. The better grades, folding board, etc., are put up in 100-lb. bundles, and are wrapped in mill wrapper, similar to the wrapping papers.

Straw (corrugated) board may be packed in bundles or shipped in rolls.

102. Packing Rolls.—Some papers other than newsprint are also shipped in rolls; the process is similar, except as varied according to grade, weight, and size. Two common types of slitters are used: the disk type, shown in Fig. 3; and the score-cutter type, shown in Fig. 2. Both of these types have been fully described in Section 1. The strips of paper, mere ribbons in the case of gummed tape, ticker tape, addressograph rolls, paper for spinning, etc., are wound on a shaft, with or without a paper or wood core. In the latter case, the shaft is usually split, so a segment can be withdrawn, thus making it easy to remove the main part of the shaft. In such rolls, and in some where cores are used, a wooden plug is driven into either end of the hole left by the shaft; but for narrow rolls, only one plug is needed. The plug, which should be of wood and perfectly round, is bored with a hole through the center. The use of iron cores is becoming less common.

The diameter of the rolls depends on the use to which the paper roll is to be put. Newsprint is generally 32 inches in diameter; while counter rolls and wrapping paper are generally 9 inches in diameter and from 9 inches to 36 inches wide. Toilet paper and paper towels are perforated by means of an attachment on the slitter, which also counts the sheets perforated, and the rolls are wound to contain a certain number of sheets. Straw board and folding box board are also frequently shipped in rolls. Some book and magazine papers are shipped in rolls, either machine finish or supercalender finish (S.C.). Stock for coating, either for printing or for wallpaper, and paper for other treatment, as abrasive papers, blueprinting, roofing felt, carbon copying, etc., must be shipped from the paper mill in rolls.

103. Wrapping the Roll.—The wrapping of rolls is a simple operation; but it must be done carefully, in order to protect the product and give it an attractive appearance. A strip of heavy paper, sometimes of a distinctive color, a little wider than the roll and long enough to wrap about three times around the roll, is used to wrap the roll. One end is tucked under the free end of the paper, and the wrapper is put on tight, overlapping an equal distance on either side. The free end of the wrapper is

pasted down, and the ends are folded in. Over these ends is pasted a header of stiff paper, cut approximately round. The rolls are then stood on end, and weights are placed on the top headers. A machine has been successfully developed for holding the heads in place until well stuck, while the roll remains horizontal. Sodium silicate is the usual adhesive. Rolls of paperboard are usually bound top and bottom with steel tape.

104. Packing for Export.—Paper that is to be shipped abroad requires special packing. The sizes of the bundles, cases, and rolls are usually different from those required for domestic shipment; the customer's shipping directions must be carefully followed, or the mill is likely to lose the customer. The cases that contain fine papers are bound with thin strips of iron. Other flat papers are often crated under pressure, with a wooden frame, top and bottom, bound together with similar strips of iron. Newsprint and other rolls are sometimes wrapped in extra layers of heavy paper, with, perhaps, a head on either end, held together by a long bolt that runs through the center. Some shippers of newsprint encase the roll in slats, nailed to wooden heads and bound with belts of band iron. Shipping cases are commonly lined with waterproof paper.

PREPARING AND LOADING CARS

105. Examining Cars.—The final operation at the mill is to load the paper into the freight cars or, less frequently, into a ship. The secret of shipping successfully is to load solid, so the cases or rolls have no chance to slide, rub, or tumble.

The first step is thoroughly to examine the car. Leaks in the roof are detected by closing the doors and noting where daylight shows through. A car with a leaky roof should be rejected, since paper shipped in it would be damaged by rain entering through the cracks. Small cracks in the sides or ends of a car must be covered with paper on the outside of the car. Any projecting nails or bolts may be found by passing a piece of straight board around the sides and over the bottom of the car. Such projections must either be removed or covered with nine thicknesses of wrapper or a piece of board, particularly when paper is shipped in rolls or bundles.

106. Lining Cars.—A large newsprint mill has found that the less the amount of lining put in the cars the better, if the car is in good condition; but it was necessary to line 90 per cent of the cars received. The old method of lining consisted in folding heavy wrapper so as to give it nine folds and nailing this around the car, so the upper outside band on the roll would rub on this padding. These two papers (lining and covering) would rub together and form lumps, which worked into the roll and caused a great deal of waste. Several methods were tried to eliminate this loss; and it was found that when the paper rubbed against a smooth surface of wood, it would not chafe or roll into balls.

Several methods of lining with wood were tried, and the following was found to be the most satisfactory: Strips ½ in. by 4 in. by 16 ft., planed on one side, with a bevel edge, are nailed around the inside of the car, the wood being the height of the outside bands of a roll, one on the sides of the car and two on the ends, at top and bottom of the rolls. The door posts are then padded with nine thicknesses of heavy wrapper; this is nailed to the sides of the door, then folded inside of the car, so as to cover the ends of the strip, and nailed. When a car has a good, smooth surface inside,—no bolts, nuts, or other protrusions,—paper is put only on door posts, no strips inside. When nuts and bolts are sticking out on door posts, place a 1-inch board over them all, and nail it solid; then put a padding of paper over this. On automobile cars, put a piece of plank, 2 in. by 6 in., planed, bevel edge, between the door posts of the small doors; all door posts are then padded with nine thicknesses of wrapper, so covering the ends of the 2 in. by 6 in. plank as to give a smooth surface in every case.

107. The Car Floor.—When the floor is in bad condition, there being bolt heads, holes, etc., the holes, if not too large, are covered with several thicknesses of wrapper, marking a heavy line where the hole in the floor is, so the men in loading will know there is a bad floor and where the hole lies. This is much to be preferred to putting boards on the floor; for, when the holes are covered with boards, it is very hard to keep all corners properly covered and avoid dents in rolls. Bolt heads are covered with folded strips of paper.

If there is oil or tar on the floor, the car should not be used. In one instance, a car that had oil spilled on the floor was loaded.

The oil did not show to any extent when the car was conditioned; but when the car had arrived at its destination, the oil had been absorbed by the paper, in some rolls rising as high as four inches.

108. Arranging Rolls, Cases, etc., in the Car.—Cases are fairly easy to handle; they are usually left on end as they are dropped off the two-wheeled truck, and they are inched into place with the toe of the truck. Small boxes are generally placed flat, and are often piled. Rolls are almost invarably placed on end. The rolls will seldom fill a car completely, and the necessary bracing must be carefully done. Don't be stingy with lumber—there are many bumps in a hundred-mile journey. A piece of 4 × 4, preferably beveled, and padded with several thicknesses of wrapper, is placed tight against the roll and held by wire nails, which are driven *vertically* into the floor. Padded planks, 3 × 4 or 2 × 6, are used to brace the rolls apart at the middle of the car, and to protect the rolls at the doorway.

A record is kept of the weight and number of each roll.

Finally, the door is closed, locked, and sealed by fastening strips of paper with laths over the cracks of the doorway. With the new steel cars a special method of sealing the door has been devised. This is illustrated in Figs. 20 and 21.

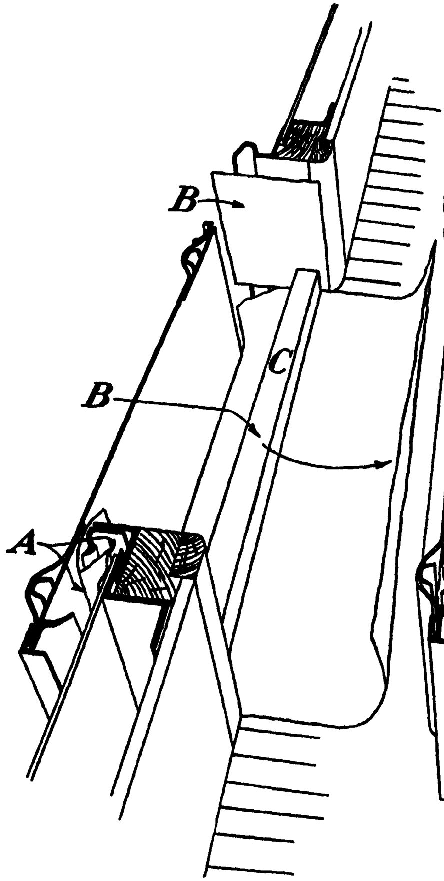


Fig. 20.

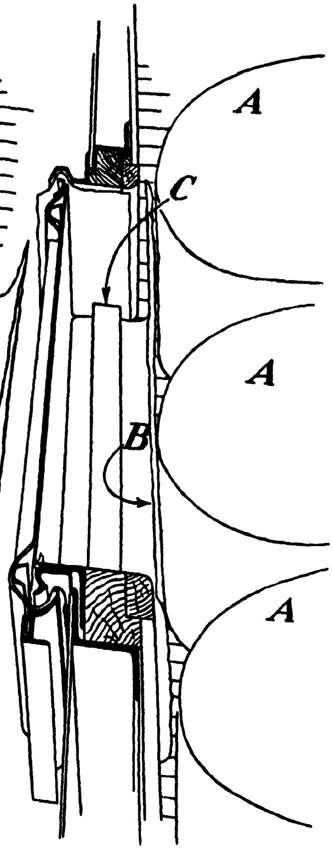


Fig. 21.

Fig. 20.—Arrangement of paper at car door. *A*, wrapping paper full height of door, to be given sharp folds as shown and inserted between door and frame to form seal when door is closed, as in Fig. 21; *B*, wrapping paper to be laid over threshold plate, turned down between plate and door and held down under wood strip *C*, and extending at least 3 feet inside the car; *D*, wrapping paper full height of door, inserted between door and frame to form seal when door is closed.

Fig. 21.—*A*, rolls of newsprint paper; *B*, wrapping paper laid against newsprint rolls, acting as an apron to catch dirt and snow; *C*, board or plank jammed into door opening.

PAPER FINISHING

EXAMINATION QUESTIONS

1. What operations may be performed in the finishing department?

2. Describe the routing of the work in the finishing rooms, and state what factors govern it.

3. What is the function of (*a*) the rewinder? (*b*) the sheet cutter? (*c*) the layboy? (*d*) the automatic counter and marker? (*e*) the overlapping delivery?

4. (*a*) When is it necessary to use the rewinder and cutter? (*b*) How is the size of the cut sheet regulated?

5. (*a*) What causes broke on the cutters? (*b*) How may this loss be kept down?

6. Describe a supercalender and explain its purpose.

7. (*a*) What is a fly roll? (*b*) Why is it used on the supercalender?

8. (*a*) Mention the various types of supercalender drives and state their advantages and disadvantages. (*b*) Why is it necessary to have two speeds?

9. (*a*) Why should loft-dried papers be conditioned? (*b*) Explain the operation of conditioning.

10. (*a*) How does a sheet calender differ from a supercalender in regard to construction and operation? (*b*) What causes sheet-calender broke?

11. (*a*) Describe a plater. (*b*) For what kinds of finish is this machine adapted?

12. Explain the process of making up the form.

13. (*a*) What classes of paper are pasted? (*b*) Describe the making of 2-, 3-, and 4-ply papers.

14. What is the process of (*a*) embossing? (*b*) friction glazing?

15. (*a*) Describe a trimming machine. (*b*) What precautions should be taken for accuracy? (*c*) Why is accuracy so necessary? (*d*) Name some of the rules of safety in the operation of this type of machine.

16. Why are the operations of sorting and counting so important?

17. What is (*a*) a quire? (*b*) a ream?

18. (*a*) Describe three ways of packing paper for shipment. (*b*) What precautions should be taken with respect to the freight cars?

19. What should be the general atmospheric conditions of the finishing rooms?

20. Name the hazards of each of the machines used in the finishing room.

SECTION 4

COATED PAPERS

(PART 1)

THE COATING PROCESS

By NORMAN CLARK AND E. SUTERMEISTER

NOTE.—The Joint Textbook Committee gratefully acknowledges the valuable assistance, in the preparation of this Section, received from H. G. Rappolt, Frank Egan, J. J. O'Conner, and others.

INTRODUCTION

USES AND VARIETIES

1. Historical.—Coated paper was first developed commercially about 1880, or a little later, because of the demand for better printing results; and since it was used largely for illustrations, it was sometimes called 'fine cut' paper. Its relative unimportance in early years is shown by the fact that it is not mentioned in "Chemistry of Paper Making," which was published in 1894. As first made, a thin layer of clay and glue was applied to the surface of a web of paper, which was then dried and calendered. In the middle 90's, casein began to replace glue as an adhesive and is now used almost exclusively. Starch has not had any marked success as a full substitute for casein, but it has been used for many years, and is still being used satisfactorily in certain grades of paper.

The original coated papers were surfaced with clay, but modern practice has broadened the field to include many other pigments, as blanc fixe, satin white, precipitated chalk, lithopone, titanium dioxide, alumina, talc, etc., each of which has certain desirable characteristics.

As first made, coated papers filled a place for which no other paper was satisfactory. Since then, they have had to compete

with greatly improved supercalendered plain papers, while the present tendency is to replace the coated with a so-called *semi-coated* paper, which is made by applying a much thinner coating at high speed on the paper machine, or as a separate operation. This latter type of paper at first competed only with the lower grades of coated papers; but with increased experience, it is being improved very materially. It is described briefly later under Machine Coating, Art. **73.**

2. Classification.—Strictly speaking, the term *coated* applies to "any paper, board, or cardboard to which has been applied a coating of any character or substance." This would include such varied products as abrasive papers, carbon tissues, coated boards, gummed papers, photographic paper, wallpaper, metal papers, foil, transfer, and numerous papers that were first developed for improved printing. The latter are used for lithograpic work, magazines, books, and especially catalogs and other advertising matter, which are more generally classified as *book papers.* More recently, these have developed into a great variety of special or decorative papers, sometimes called *fancy papers*, which are utilized chiefly for their appearance, though they may be required to possess special qualities, such as waterproofness, color, ability to take varnish or lacquer, etc., and are also, in many cases, expected to print well. In these papers, the customer frequently expects certain qualities that cannot be combined in one sheet.

Although many of the operations in coating papers of widely differing grades may have points of similarity, the present text relates specifically to book and fancy papers; but where necessary for a good general understanding of the industry in general, notes on other grades are included.

3. Purpose and General Processes.—The primary object in the coating operation is to produce a sheet with an even, semi-absorbent surface for printing; and this is effected by covering the fibers on the surface of the paper and filling the hollows between them with finely divided mineral matter, mixed with an adhesive or 'size.' When such paper is calendered, there results a smooth, even surface, which reproduces the halftone dots of the printing plate much more faithfully than any plain paper.

Originally, the coating mixture was spread on sheets of paper by hand, being applied by a brush and then made more uniform by rapid strokes of a finer brush. Modern methods apply the coating to a continuous web of paper on one or both sides at the same time, and at speeds up to 700 ft. per min. The spreading is done by brushes, blades, rolls, or a blast of air.

The essential materials in a **coating mixture**[1] may be tabulated thus.

Mineral matters: (*a*) White—clay, blanc fixe, satin white, talc, calcium carbonates, lithopones, titanium dioxide. (*b*) Colored—ultramarines, umbers, siennas, ochers, lakes.

Adhesives (sizes): casein, glue, starches, gum.

Waxes: carnauba, beeswax, ceresine, paraffin.

Waterproofing agents: shellac, Manila gum, formaldehyde.

Special materials: dyes, lakes, pigments, powdered metals, alkalis, softening agents, defoamers, wetting agents.

4. Varieties of Coated Paper.—It is not possible to give a complete list of coated papers, since new grades and products are constantly being developed; neither can a hard and fast classification be made, since there is more or less overlapping of the grades. The following list gives some of the more common grades, with notes as to their uses and characteristics.

BOOK.—This term loosely covers all papers intended for printing, such as actual book, lithograph, catalog, advertising papers, label, proving plate, etc.

FRICTIONS AND FLINTS.—These take their names from the machines on which they are finished. They contain wax, to enable them to take a very high, glossy finish, and are used principally for box coverings.

PLATE.—This is a flat, supercalendered paper, harder sized than frictions; used for labels, signs, kindergarten supplies, and box coverings; now required to be fully waterproof.

LABEL.—A hard-sized clay-coated sheet; used chiefly for printed labels.

LITHO.—With the exception of some waterproofs, this is the hardest-sized sheet made; it must be thus sized to withstand the repeated impressions on the lithographic press and the moistening

[1] The coating mixture as applied to paper is termed *color* in most coating plants; but throughout this Section, the word color is used only in its commonly accepted sense.

PROPERTIES OF COATED PAPERS

	Usual trade size (inches)	Ream weight (pounds)	Weight standard size 25 × 40	Fiber furnished (per cent)				Bursting strength (pounds per square inch)	Sizing	Uses
				Sulphite	Soda	Gr. Wood	Rags			
Friction and flints....	20 × 24	17	35	30 70	.. 30	70	..	10–15	Medium	Box covers
Plate...............	20 × 26	17–50	35–104	70	30	..	..	12–35	Soft	Labels, box covers, signs, kindergarten supplies
Book..............	25 × 38	40–80	42–84	60	40	..	..	10–20	Soft	Printing matter
Dial...............	22 × 28	70–160	114–260	80	20	..	..	50–80	Hard	Clock and watch faces
Playing card.........	22 × 28	45–115	73–187	70	30	..	..	20–50	Hard	Playing cards
Litho...............	25 × 38	35–90	37–95	70	20	..	10	15–40	Hard	Lithographic work
Boxboard...........	....	0.01–0.03	....	Long manila liner—short—softer middle				40–70	Medium	Light boxes

Enamel.............	25 × 38	35–125	37–132	70	30	..	..	15–60	Medium	Box covers—illustrated
Translucent.........	25 × 38	110–150	116–158	70	15	..	15	50–70	Medium	Embossed work—lithography
Proving plate........	22 × 28	50–80	81–130	45	15	..	40	15–30	Medium	Lithography
Tablet...............	22 × 28 22 × 28	50–80 50–120	81–130 81–195	70 Long fiber manila	30	..	..	15–25 30–70	Medium Medium	Pads
Label...............	20 × 24	17–50	35–104	50	..	50	..	10–20	Hard	Printed labels
Enamel blotting.....	22 × 28	90–180	146–292	..	..	..	100	.....	Hard (one side)	Printed blotters
Metals..............	20 × 24	12–50	25–104	Glassine, manila, grease-proof, groundwood, or free sheet				.....	Medium	Fancy box covers
Micas...............	20 × 24	20–28	42–58	High soda to give bulky sheet				.....	Soft	Fancy box covers
Waterproofs.........	20 × 24	20–35	42–73	100 45 35	 15	.. 55 25	 25	10–30	Medium	Box and notebook covers

Note.—Where several sets of figures are given for fiber furnish, several classes of paper are indicated. The figures given herein are about the average.

that this involves. Newly developing gloss inks are changing the requirements for this paper.

BRUSH ENAMEL.—An important, semi-gloss, velvet-finish paper, named after the method of finishing the surface; used largely for illustrations, box coverings, and cigar bands.

TRANSLUCENT.—A heavily coated sheet of good quality; used principally for embossed work.

DIAL.—A hard-sized, well-made sheet; used for clock and watch faces.

PLAYING CARD.—Made from 2- to 5-ply material; the outside, or liner, is coated and is pasted to the relatively soft middle with flour or starch paste.

WATERPROOF.—This is generally a two-coated paper, consisting of a hard-sized base coat and a top coat of shellac or casein, or a mixture of the two; used for high-class box coverings, notebook covers, imitation leather for suitcases, etc.; usually embossed.

MICAS.—These are fancy box coverings, coated with mica tinted with aniline dye. They are usually printed in a white design on an intaglio or surface machine, and then embossed.

METAL.—Coated with various powdered metals, tin, aluminum, zinc, or bronze, mixed with the adhesive; may be friction- or supercalendered; used plain or embossed, chiefly for box coverings. The body stock for this grade varies all the way from groundwood to glassine.

5. Table of Properties of Coated Papers.—In the table on pp. 4–5 Clark gives a list of the more important grades of coated papers, and shows the usual size and weight, the approximate fiber furnish, the bursting strength, and the sizing of the paper for each grade; the last column gives the uses to which the finished papers are put. The bursting strengths are given in pounds per square inch as recorded by the Mullen tester (see Section on *Paper Testing*), and the sizing as determined by the cell method, using 100 ohms resistance. The following values are assigned to the sizing: soft, up to 1 min.; medium, 1 to 3 min.; hard, over 3 min.

PROCESSES

6. The Five Steps.—Five steps are involved in making coated paper: (1) the preparation of the coating mixture; (2) its applica-

tion to the paper; (3) the drying of the web of coated paper; (4) calendering or surface-finishing operations; (5) cutting, sorting, packing, and shipping. These steps will be discussed in this order.

7. Layout of Coating Mill.—The layout of a coating mill is shown diagrammatically in elevation in Fig. 1. Room *A* runs the full length of the building and is a receiving room for raw materials and equipment; the basement *B*, also running the full length, is used for storage of materials, such as clay, casein, etc., and is connected with the other levels by an elevator, which is not shown. In room *C*, the stock mixtures of sizes, waxes, and

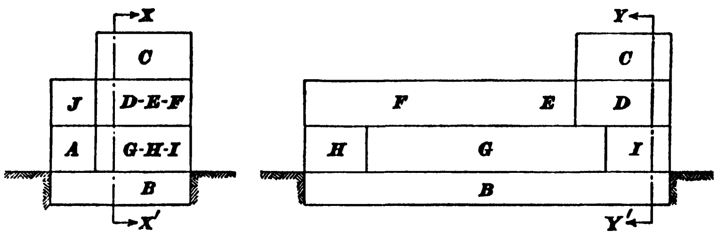


FIG. 1.

waterproofing materials are prepared, the base pigments mixed, and coloring materials handled. Room *D* is where the ingredients are compounded in the right proportions for the paper being made, and from which the mixture goes to room *E*, containing the coating machines. The portion marked *F* contains the drying lines of the return-line type. In room *G* the coated paper is calendered, brushed, or otherwise finished, cut, and sorted, and then passes to the packing and shipping room *H*. The office is at *I*, and the room *J*, which runs the entire length of the building, is used for the storage of rolls of paper, either uncoated or coated, but not finished. The left-hand view is a section on *Y-Y'*; the right-hand view is a section on *X-X'*.

This arrangement utilizes gravity to a great extent and is economical of power and labor. It must be understood, however, that it may be varied to suit local conditions, and that the diagram is, therefore, only an indication of a desirable layout in which the operations follow in *logical order*.

RAW MATERIALS

PAPER

8. General.—Before combining the various ingredients into the coating mixture as applied to the paper, many of the materials must go through certain preliminary operations. Some of these are carried out as measures of convenience only, while others are absolutely necessary, because the raw materials as received are not in a suitable state to use. Characteristic of the first named is *clay*, which may be, and sometimes is, used in the dry condition, but which is easier to handle if made into a slurry with water. Casein, on the contrary, is received in a dry condition, and has to be dissolved in water with the aid of alkalis before it can be used. In the layout shown in Fig. 1, it is assumed that these preliminary operations are carried out in a separate room; but it is more frequently the case that they are scattered through various parts of the plant, largely as a matter of necessity. However, the separate room is considered to be much more efficient.

9. Paper as Raw Material.—Paper, regardless of kind or grade, is to be considered as one of the papermaker's most important raw materials. In some cases, the paper is made in the same plant that uses it, but it is often purchased from paper mills by independent coaters. Paper for coating is variously termed *base paper, body stock, coating paper, backing* (wall-paper), etc.

10. Properties.—The quality of the paper used for coating—generally called **body stock**—is of very great importance, but is difficult to describe, because many of the properties demanded are of an intangible nature. This fact makes it very hard for the coater to tell the manufacturer of his body stock just what he wants, and it leads to many misunderstandings, which might be removed by closer cooperation. In the following paragraphs an attempt has been made to describe some of the qualities that are desired in paper that is to be used for coating. Many of the properties of the paper that influence the coating results cannot be measured or expressed numerically; but for such as can be measured, reference should be made to the Section on *Paper Testing*.

11. Formation of Sheet.—All papers for coating should be as uniformly closed up as is possible, taking into consideration the strength required in the coated paper and the nature of the fibers used. Paper that is wild and bunchy does not absorb the coating evenly, and when it is calendered, it shows a disagreeable, mottled appearance. This type of paper is especially bad for high-grade book paper; for in calendering all parts down to an equal thickness, the thin and thick places result in different densities, which take the printing ink differently and give the halftones or solid blacks a mottled appearance.

The uniformity of formation of the sheet is limited by a number of factors, including the cost, as affected by the speed of the paper machine; and, above all, the strength and folding qualities demanded in the coated paper. High folding and tearing strength, and durability when handled roughly, do not go hand in hand with the most uniform formation.

12. Strength.—The strength of paper as expressed by its tear has been found to be a valuable indication of the satisfaction given by the coated paper when mechanically handled, as in folding machines. The tearing strength can be measured by a number of instruments, but great difference of opinion exists as to just what is desired. It probably varies with different classes of paper, and it should be studied carefully in each plant in the light of the demands of its particular customers.

13. Finish.—The *finish* desired by the coater is comparatively slight, but it is essential that it be uniform across the sheet, in order that the coating may brush on uniformly. If too high a finish is given to the paper before coating, more adhesive is often required than for a sheet of lower finish. This may be caused by the fact that the harder calendering gives less 'tooth' to hold the adhesive.

14. Thickness.—Uniformity of thickness throughout the sheet is essential if a uniform coating is to be obtained. If one edge is thinner than the other, it will take more coating, and the two edges of the sheet will take a different gloss on finishing and will print differently. This factor of thickness is closely related to formation, for it is local variations in thickness that cause part of the trouble with *wild* paper. As would naturally be supposed,

the thickness is more apt to vary in heavier sheets than in those of lighter weight.

15. Slack Edges.—This trouble is closely related to thickness; for if the paper is thinner on one edge than on the other, a slack edge will result. When running such paper on the coater, it is very difficult to maintain the tension uniformly enough. This follows through in subsequent operations, and much waste from breaks and cuts is apt to result.

16. Curling.—Paper from rolls will often curl badly on one edge when drying on the lines after being coated. This causes waste of paper and creates delay at the reels.

17. Fuzz.—Fuzz on paper to be coated is very objectionable. The coating mixture, and especially the coloring matters used, seems to collect around the base of each upstanding fiber, and when such paper is calendered, it shows considerable variations in finish and color.

18. Feel.—This is one of the intangible factors that cannot be measured, yet it is of much importance. Probably the best that can be said is that the most satisfactory paper has a velvety or leathery feel, and is not dry, harsh, or brittle when crumpled.

19. Color.—The nearer the color of the body stock approaches that of the finished paper the better, for brush marks or other slight differences in thickness are then not so noticeable. If there is a marked contrast between the coating and the body stock, it is very difficult to produce a sheet of satisfactory appearance, because slight local differences show plainly, though they may not be serious enough to affect the printing results. As a rule, the color of the body stock should be as good as possible, for the better the color of the body stock the better will be that of the finished coating.

Where body stock is purchased, rather than made at the plant where the coating is applied, the maker should consider the special preference of the coater for certain tints of white. It is most important that the rolls in a given shipment shall all be the same, though, unfortunately, this is often not the case.

20. Dirt.—The cleaner the body stock the cleaner will be the finished coated paper: it is only the very small specks of dirt that are hidden by the coating; the larger ones, especially those of a dark color, show through. It frequently happens that the heavy

calendering given to the coated product makes the dirt and shives more noticeable than they were in the uncoated paper. The cleanliness required is greater in the higher grades of coated papers; but in the low grades, where groundwood is used for colored papers, shives should be held down to a minimum. Shives take up certain dyes more strongly than other fibers, and their presence results in a paper mottled with the more deeply colored shives.

21. Sizing.—The sizing of body stock is of considerable importance to the paper coater. If the paper is slack sized, the adhesive in the coating mixture is absorbed to too great an extent by the body stock, and weak coating results. This is especially true when glue is used as the adhesive; but it is also important when using casein and starch. It has been found that there is a minimum point in sizing, below which trouble is likely to be encountered; but that above this point, increasing the degree of sizing does not improve matters greatly. The unsatisfactory state of affairs with regard to methods of testing for sizing and the variations in the requirements in different coating plants make it impossible to establish any general standards for body stock.

WHITE PIGMENTS

22. Clay.—The clay used in coating is a hydrated aluminum silicate of slightly varying composition and with small amounts of impurities. The best grades were formerly obtained from England, but changes in the treatment and manufacture of American clays have so greatly improved them that they are now equal or superior in many respects to English clays. These changes have been toward better color and brightness and smaller particle size, which means higher gloss and better printing qualities in the coated paper.

23. Preparation of Clay Slurry.—As mentioned in Art. **8,** clay may be added to the coating mixer in dry condition as received, and many mills still use it that way. This practice is objectionable, because variations in the moisture content may cause variation in the solid content of the coating mixture, as well as in the proportion of clay to adhesive. It also causes loss of time in preparing the mixture and in adjusting the ratio of clay to

adhesive, if the proper strength of coating is not obtained at the first trial.

A preferable method is to mix the clay with water in definite proportions, and measure this out by weight or volume when making the coating mixture. Such a clay *slurry* will vary in fluidity, according to the kind of clay used and the proportion of water used with it. Addition of about 0.5 lb. of sodium silicate to 100 lb. of dry clay is of great assistance in making the slurry fluid. There is then generally no difficulty in reaching 60 per cent solids or more, and at the same time the slurry will be in proper condition to pump readily. Other alkalis, as caustic soda, soda ash, trisodium phosphate, etc., may be used with similar results. The quantities of any of these must be adjusted to the kind of clay used.

24. Method of Preparation.—Preparation of the clay slurry may be effected in a number of ways, probably the simplest being to add all the required water to the mixer, dissolve the silicate in it, and then add the proper amount of dry clay. With efficient agitation, this will work up to a smooth cream in a short time: but if the clay is mixed with the water before the silicate is added, serious balling up is likely to occur.

Another method, recommended in some plants, is to add a quarter of the total water to the tank, start the agitator, and add a quarter of the clay; this is followed by more water and more clay, alternately, until the full charge has been added.

There should be at least two large mixers for the clay slurry, one to be drawn from while the other is being filled, mixed, and tested. Before use, a sample from each tank should be tested for solid content, and if found incorrect, more clay or water should be added to bring it to the standard dry content. This procedure will ensure uniformity in the clay delivered to the coating mixers.

There are differences of opinion as to the length of time of agitation. Some claim that the longer the agitation the better the clay; others assert that agitation should be stopped as soon as mixing is complete, because of rapid evaporation due to the heat produced. If silicate is used to thin the slurry, mixing must be continuous, to prevent the settling of the coarse particles of the clay into a very dense layer on the tank bottom.

25. Testing Clays.—Clay is by no means the inert material it was formerly considered, and even now it is not fully understood what a great influence the nature of the clay may have on the coating mixture and the coated paper itself. The present methods of examining clay are entirely inadequate to prove its true value as a coating material, since only a practical trial will show the spreading characteristics of the coating mixture formed from it and the qualities of the finished paper in which it is used. The tests most often applied to clay are those for moisture, color, grit, casein required, and the viscosity it imparts to the coating mixture.

26. Testing Clays for Moisture.—Moisture may be easily determined by weighing out a representative sample and determining its loss in weight after drying at 105°C. English clays may contain from 6 to 18 per cent moisture, with an average of about 10 per cent: American clays usually contain considerably less.

27. Testing for Color.—Color is usually determined by crushing the clay to a powder and pressing it down on a smooth surface side by side with a standard clay. This can be done with a spatula or piece of glass; at the line where the two clays are in contact, any differences in color or brightness are readily noted. A better method is to use a recording spectrophotometer or one of the modern colorimeters that give a permanent record of the color of the sample.

Either of the two latter methods gives the color of the clay alone, and since this is considerably and variably affected by the casein used in the coating, the relative results are not necessarily the same as in the coated paper. This drawback may be partially overcome by preparing a coating mixture with the clay under consideration and with the amount of casein found to be necessary for a satisfactory coating. If this is spread in a very thick layer—60 lb. per ream per side, or more—the color of the body stock is without influence, and only the color of the coating as a unit affects the eye or the measuring instrument. Even this procedure is not perfect, as it fails to take into consideration the effect of calendering; in fact, it is nearly impossible to arrange a really good test for this factor.

28. Testing for Grit.—Grit may be determined by washing a weighed sample of the clay through a 300-mesh sieve with a gentle spray of water. When no more will wash through, the residue on the screen is dried and weighed as grit, which should be examined with a lens to determine its nature. Unless the amount of grit is fairly considerable, the quantity present is probably not of much significance. Further information on clays will be found in the Section on *Fillers and Loading*, Vol. IV.

29. Casein.—The testing of casein is described in Arts. **46–48.** It should be noted, however, that it is necessary to use the *same* casein for all the clays that it is desired to compare. In the past, English coating clays have been known to vary as much as 60 per cent in the amount of casein they required.

30. Viscosity.—The viscosity of a coating mixture is determined as described in Art. **48.** Since there is no constant relation between the viscosity of a clay-water mixture and a coating mixture containing casein, tests of the former are of practically no value in indicating the character that clay gives to a coating mixture.

31. Blanc Fixe.—This is an artificially prepared barium sulphate, which may be obtained from its makers either as a dry powder or as a paste containing about 30 per cent of water. The paste tends to separate in the casks and settle very densely, so it is best to transfer it to mixers and reduce it to a uniform consistency before use. It is well to add a little water during this process, in order to reduce the strain on the agitators.

Moisture tests on blanc fixe are quite useless unless the contents of the entire container can be mixed very thoroughly. The most important tests are for color, grit, and fineness of particles; in some cases, a test for acidity may be desirable. Fineness of particles can be determined with sufficient accuracy under a high-power microscope, by comparison with a known standard having satisfactory qualities.

32. Satin White.—This white pigment is made by mixing slaked lime and aluminum sulphate (alum); it is generally purchased by the coating plant in the form of a paste containing about 70 per cent of water, when the sample is dried at 140°C. It is a strongly alkaline pigment and is, in all probability, calcium sulpho-aluminate $3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 31H_2O$. Its physical

characteristics vary according to the way the materials are combined, *i.e.*, whether the alum is in the form of coarse lumps, finely ground, or in solution. It is used to impart a high gloss and brilliant white color to the coating, but it also aids in making a casein coating water resistant.

When using satin white, it is best to remove from the casks or drums and mix several lots together in heavy agitators or dough mixers. It is not necessary to add more water, but the mixing should not be too prolonged, since the satin white then becomes warmer than is desirable for incorporating in the coating mixers.

In testing satin white for moisture, it is recommended that a temperature of 135° to 140°C. be employed. Below this temperature, there is a progressive loss in weight as drying temperatures rise, but above it there is little change. When dried at this temperature, some of the water of crystallization of the satin white is driven off. If it be desired to know the air-dry weight of the material that would be present when the coating is dried at low temperature, the satin-white sample must also be dried at that temperature. This is an extremely slow process, and for comparison of samples among themselves, the higher temperature is to be preferred.

The alkalinity of satin white is also an important consideration: it may be determined by titrating a weighed sample with standard acid, using phenolphthalein as an indicator. It is customary to express the result as the per cent of free lime $Ca(OH)_2$, though it is doubtful if any such material is present.

Satin white should be tested for color occasionally, though, as a rule, this does not vary much from shipment to shipment. It should also be examined for grit, and be given a microscopic examination, or even a complete chemical analysis if there is any question of adulteration.

33. Precipitated Chalk.—The various forms of precipitated chalk (calcium carbonate) have recently become of much more importance as coating pigments. They vary in particle size from a relatively coarse product that tends to give a dull surface to the paper to an extremely fine material that can be used in high-gloss papers. They are prepared by the action of soda-ash solution on slaked lime, or by passing carbon dioxide into milk of lime, and may be obtained in either dry or paste form.

Probably the most useful test that can be applied to these products is a microscopic examination for fineness of particles. Uniformly small individual particles are desired, and coarse particles or aggregates are regarded with disfavor.

34. Other White Pigments.—Among the white pigments sometimes used are: titanium dioxide, either as such or as a combined pigment with a barium sulphate or calcium sulphate base; zinc sulphide, or the various lithopones having this as a con-

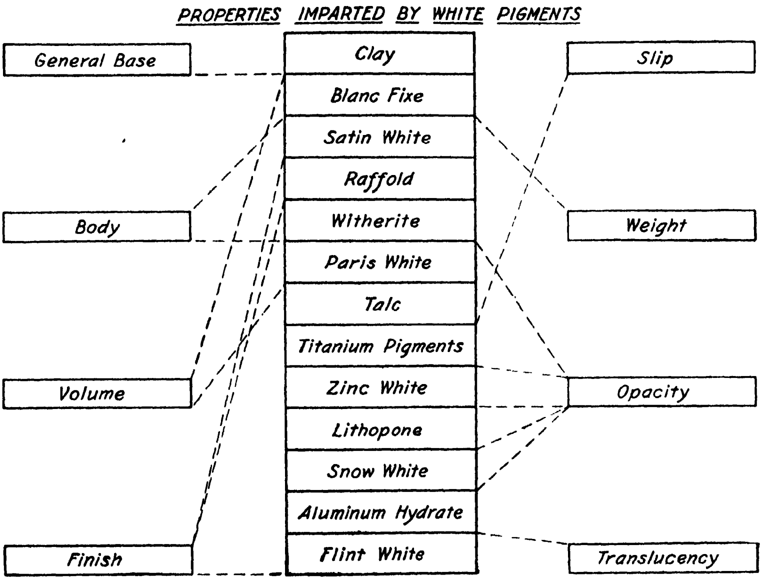


FIG. 2.

stituent; barytes; talc; zinc oxide; etc. In the case of the zinc and titanium compounds, they are generally used in relatively small amounts to impart opacity and improve color rather than as the chief constituent of the coating mixture.

35. White-Pigment Chart.—In this chart, Fig. 2, will be found a list of the white pigments available to the paper coater, and so arranged as to show the properties imparted by each. Each pigment has a definite purpose, and the coater man can vary the properties of the sheet tremendously by proper selection of pigments. In this chart are several pigments not heretofore mentioned, as follows:

RAFFOLD: prepared by treating slaked high-magnesia lime with soda ash, as in the causticizing process.

PARIS WHITE: the whitest and purest form of whiting made from natural chalk.

WITHERITE: a native barium carbonate reduced to proper particle size.

ZINC WHITE: is zinc oxide, while *flint white* and *snow white* are trade names for special mixtures of white pigments.

A comprehensive table of the composition and properties of white pigments is given in the section on *Fillers and Loading*, Vol. IV.

COLORED PIGMENTS AND DYES

36. Use of Coloring Matters.—The use of coloring matters in making book papers is, in the great majority of cases, confined to the small amounts of blue, red, and yellow that are necessary to produce the various shades of white and cream demanded by the trade. There are, however, many colored papers and specialties made in which large quantities of colors are consumed, and a few remarks regarding their characteristics and uses are therefore appropriate. An extensive treatment of coloring materials and operations is given in the Section on *Coloring*, Vol. IV.

37. Colored Pigments.—These are insoluble solids, which are mixed in a finely divided state with the materials whose color is to be altered. They are, as a rule, very fast to light, but many of them give somewhat dull, flat tones to the coating. If used in large quantities, they prevent the paper from taking a finish as high as those in which lake colors are used. For this reason, pigments are often used in conjunction with lakes.

The following pigments are used in the coating process:

Reds: Venetian red, Indian red, burnt sienna, red lead, orange lead, and vermillion.

Yellows: chromates of lead, barium, zinc, and strontium.

Greens: emerald green, cobalt green, malachite.

Blues: ultramarines, Chinese, Prussian, and cobalt blues.

Browns: umbers, Vandyke brown.

Blacks: lampblack, vegetable black, carbon, bone, ivory, and drop blacks.

Pigments should be tested for grit and moisture, but above all for coloring power. This may be done by mixing a little of the pigment with clay and comparing the mixture with a standard sample of the color similarly treated. A permanent record, which may be used for future comparisons, may be made by preparing a coating mixture containing standard amounts of clay, casein, and color, and spreading small sheets of paper with this. When dry, these may be compared with the standard sheets, and the relative strength of the colors established.

In using many of these colored pigments, it will be found that they contain small, hard lumps that do not wet out to a smooth paste and are too small to be removed by the screens through which the coating mixture is passed. These are apt to cause color streaks and other troubles in the paper. In many cases these difficulties can be avoided by grinding the pigment with water in a pebble mill before attempting to use it. This often increases the coloring power of the pigment to a marked extent.

38. Lake, or Pulp, Colors.—A **color lake** is generally understood to mean an artificial pigment prepared by precipitating a dye upon some base such as clay, barium sulphate, alumina, etc.

The term **pulp color** is also applied to these lakes but is sometimes extended to cover pigments sold in the paste form, such as the chrome yellows.

Lakes may be made from either basic or acid colors, and sometimes basic colors are used to top off the acid colors to give brilliancy to the lake. Because of their fugitiveness to light, basic dyes are seldom used alone in preparing lakes. The number of color lakes is large, but their nomenclature is more uniform than in the case of dyes. Differences in the working qualities of lakes purchased from different manufacturers arise from a difference in the manipulation of the lake during its formation, rather than in the original colors used.

Lake colors are useful in producing deep-colored coatings of good brilliance. They are usually more fast to light and chemicals than the dyes from which they are made; but they are somewhat difficult to handle, because of the variation in their moisture content, which is not always the same in different packages of the same shipment, even when first purchased, and it changes with the time the goods are in storage. This is true even if the casks are not opened, for evaporation takes place to an appreciable

extent through the staves; but it is still more pronounced if a package stands around after part of its contents has been used. The best way to avoid trouble from this source is to bring a reasonable quantity of each lake to a predetermined standard of moisture or color strength. This means very careful testing and proper containers to prevent evaporation; but the greater certainty of securing the desired results probably justifies the added expense.

Many of the difficulties with pulp lakes are overcome by the use of *dry lakes*, made by drying and grinding the pulp lakes. These are becoming more popular because of the ease of handling at the coating plant, since there is no danger from freezing during shipment, no variation in moisture, and matching colors may be done much more rapidly and certainly. The chief difficulty is that some of these dry lakes are not easily dispersed to sufficient fineness.

39. Dyes.—For coating purposes, practically only three classes of dyes are used; *viz.*, basic, acid, and direct dyes.

40. Basic Dyes.—There is a great temptation to use basic dyes because of their great strength and brilliance; but, with a few exceptions, such as rhodamine, auramine, and methylene blue, they are very fugitive when exposed to light. Many of them tend to be decolorized or changed in shade by the alkalis in the coating mixture, and there is a further tendency to change in hue when exposed to moist heat, as occurs when the coated sheet passes through the drying lines. Basic dyes may be used with glue or an acid starch adhesive, if too much is not expected of the finished sheet.

Most dyes may be dissolved satisfactorily by making into a paste with cold water and then adding as much boiling water to the paste as is called for by the amount of dye used: stirring should be continual during dilution. There are some exceptions to this rule, as, for instance, methyl violet and auramine. The temperature, when dissolving auramine, should not exceed 160°F., or the dye will be destroyed; while with methyl violet, cold water tends to form a hard paste, and the dye should be treated directly with hot water.

Dyes should be carefully tested for strength by some process nearly approaching actual conditions of use. A satisfactory

method is to make up a coating mixture colored with a known amount of the dye and spread sheets by hand. When these are dry, they may be compared with the standard sample similarly treated. In addition to this test, they should be examined for fastness to alkalis, and be given any special tests that will show their suitability for any unusual purposes.

41. Acid Dyes.—This is the most important class from which to select colors for coating. While not so strong or brilliant as basic colors, they are much faster to light and to conditions in the drying lines. They are not affected by casein or, in general, by the amounts of alkali in the coating mixture.

42. Direct Dyes.—Nearly all direct dyes possess good fastness to light and alkalis, but are quite dull when mixed with clay. They were formerly used for rag stock, but present demands by users of this grade make it necessary to use pigments or lakes almost exclusively.

The remarks regarding the testing of basic dyes apply equally well to the acid and direct colors.

Since new dyes are being placed on the market at frequent intervals, no list of colors for coating can be made that will be of any permanent value. Such lists, together with sample cards, can be obtained at any time from the makers of, and dealers in, dyes.

ADHESIVES

CASEIN

43. Properties.—**Casein** is a nitrogenous substance that is present in milk to the extent of about 3 per cent by weight. It is prepared by acidifying skim milk, washing the curd, drying and grinding, and is usually received at the mill in such a degree of fineness that practically all of it will pass a 20-mesh screen. If too finely ground, it is more difficult to wet it thoroughly in preparing its solutions: in general, not much more than 25 per cent should pass a 60-mesh screen.

The grade or kind of casein was formerly considered to be very important, since casein produced by use of lactic acid, sulphuric acid, or hydrochloric acid gave different types of solutions and

coating mixtures. With the modern methods employed in preparing casein, these differences have largely disappeared, and it is now of no practical importance whether hydrochloric acid was used or the milk allowed to sour itself.

Before using casein, it must be changed from a dry, granular substance to a colloidal solution, usually called simply the *solution*. This is effected by soaking the casein in water, adding some alkali, and warming. Since the details vary greatly in different plants, no method of universal application can be given; those here mentioned must be considered merely as illustrative of good general principles.

44. Solvents.—The alkalis used in preparing casein solutions are generally spoken of as **solvents.** While a large number of such solvents may be used, only about six are used commercially, and these may be employed singly or in mixtures; they are as follows:

(*a*) **Ammonia** is a good solvent and is often used alone. In such cases, the dry coating is waterproof to some extent, possibly because of the loss of ammonia in the drying operations. Ammonia is generally used in preparing casein solutions for top coating.

(*b*) **Borax** acts as a preservative as well as a solvent. Under certain conditions it is unsatisfactory if satin white is used, since it causes great thickening of the coating mixture.

(*c*) **Soda ash** is a very useful solvent if used carefully. Unless a large excess is used, it causes great froth development in the casein solution. It has a tendency to produce thin solutions, which do not keep very well.

(*d*) **Caustic soda** is a powerful solvent, and because so little is needed it is relatively cheap. If too much is used, it is apt to cause chemical changes and deterioration of the casein; hence, excess should be avoided.

(*e*) **Trisodium phosphate** is an excellent solvent when used with borax and ammonia, and it gives unusually fluid solutions.

(*f*) **Disodium phosphate** is a useful solvent because, in conjunction with borax, it will produce neutral casein solutions.

In dissolving casein it is rather common practice to use more solvent than is necessary to produce a solution neutral to litmus. The following table shows the amounts of the various solvents necessary for a neutral solution, and also those commonly used.

Per cents are based on air-dry casein, and in the case of ammonia they refer to the weight of 26° solution.[1]

Solvents for Casein

	For neutral solutions, per cent	Common mill practice, per cent
Caustic soda	3.5	4 to 6
Soda ash	4.6	6 to 12
Ammonia	5.2	6 to 8
Borax	14.7	15
Trisodium phosphate	12.3	12 to 14
Disodium phosphate	....	14

45. Cooking.—Before casein can be used, it must be made into a solution, which requires that it be cooked and dissolved. It is generally agreed that dissolving the casein by heating in a jacketed kettle is preferable to blowing steam directly into the charge. Indirect heating avoids local overheating and adds no water of condensation, which would be a source of variation in the final coating mixture. Four general methods of preparing casein solutions are given herewith, any one of which will give good results.

(*a*) Water is heated to 90° to 140°F. and steam is shut off. Casein and solvents are added, and agitation is continued until the casein is completely dissolved.

(*b*) The casein and solvents are added to cold water; steam is turned on until a temperature of 140°F. is reached. Steam is turned off, and agitation is continued for 1 to 3 hours. Cold water is then turned into the jacket, and, when the charge reaches 90°F., it is ready to use.

(*c*) The casein, water, and solvents are mixed, and solution is allowed to take place at room temperature. This is much slower than the other methods.

(*d*) When a clear casein is desired for the purpose of top sizing, the casein should be added to cold water, agitated until thoroughly soaked, and then allowed to stand for an hour. After drawing off the water on top, with its content of free acid, dirt,

[1] By *ammonia* is meant ammonia water, commonly called ammonium hydrate. The 26° means the density as measured with a Baumé hydrometer; this is equivalent to a specific gravity of 0.8974.

and foamy scum, fresh water is added to the proper height, heat applied, and ammonia added.

The temperature at which the casein solution is mixed with the rest of the coating materials varies greatly in different mills, and apparently without any reason. In some mills it is used at the full temperature of the cook—140°F., or higher—while in others it is cooled to as low as 90°F.

TESTING CASEIN

46. Solubility.—Nearly all modern caseins are of satisfactory solubility, but an occasional lot will be found to be deficient in this respect. There is no established standard method for determining solubility. What each user is especially interested in is whether the casein is sufficiently soluble with the kinds and amounts of solvents that he regularly uses. This may easily be determined by soaking 50 g. of casein in 200 c.c. of water, adding the desired alkali, and warming for a short time on a steam or water bath. Inspection will then show whether any appreciable amount of insoluble matter is present.

In making this test, it is well to dilute the solution so prepared with a considerable volume of hot water, stir thoroughly, and allow it to stand for an hour. When the top portion is decanted from any settled sludge, the latter can be examined as to its nature. If it is desired to know the amount, the dilution and decantation can be repeated until all the soluble casein is washed out; the insoluble matter can then be dried and weighed. The actual proportion by weight is not so important as the volume it occupies while wet, and its physical nature—whether fine or very coarse.

47. Adhesive Strength.—This test is made by adding small amounts of casein, progressively, to a weighed amount of clay, spreading on a sheet after each addition, allowing the sheet to dry in the air, and testing it with the Dennison graded waxes. The casein may be dissolved with the alkali customarily used in the plant where the test is being made: a solution of 1 part casein in 5 parts of total solution will be found convenient.

Clay equivalent to 100 g. dry is placed in an enamelware cup or heavy casserole; and if dry clay is used, about 65 to 70 c.c. of water is thoroughly mixed in until a smooth paste is obtained.

To this is added 40 g. of casein solution (equivalent to 8 g. of casein), and after a thorough mixing, a sheet is uniformly coated with the correct weight per ream of coating.[1] The container and mixture are then reweighed, 5 g. more of the casein solution is added, and the process repeated. The amount of casein should be definitely below that which would be required, and should be carried well above full strength; from 8 to 14 parts per 100 of clay will usually suffice.

When dry apply to each sheet Dennison's graded sealing waxes Nos. 3 to 8, inclusive. This is done by melting the end of the wax stick in a low-temperature gas flame until a few drops fall, and then applying the melted end lightly to the paper to be tested. After standing at least 15 min. at some definite temperature (70°F. is a convenient standard), the waxes are removed by a quick, vertical pull while pressing firmly down on the paper. The spot where the wax was applied is then examined with a lens, to see whether any of the coating was picked off.

This test requires a considerable degree of skill and judgment for its reliable application. To get comparable results, the same clay and paper must be used in all cases. The solid content of the coating mixture must be nearly the same each time, and the coating must be applied evenly and be of a definite and constant weight per ream. This is very difficult to do unless a small coating machine is available: but it is of importance, since it has been proved that it is necessary to keep the weight of coating within 1 pound per ream on either side of the desired weight if reliable tests are to be obtained. The interpretation of the wax test is also difficult, for it requires knowledge of the use to which the paper is to be put. Some grades of paper will print safely when the coating picks on No. 4 wax but does not on No. 3; while for other purposes or grades of printing, it may be necessary to use enough casein so that picking occurs on No. 7 or No. 8 wax. It is at present impossible to establish any generally applicable standards for the wax test: each plant must establish its own standards, with due regard to the uses of its products.

48. Viscosity.—Up to the present there are no means of measuring the ability of a coating mixture to spread well under

[1] The correct weight of coating is that amount which must be applied to a certain raw coating paper that will make the finished paper have the desired weight per ream, as 60, 80, or 100 lb., 25 × 38—500.

the brushes. Viscosity tells a part but by no means all the story; however, the viscosity test is of considerable value to the paper coater. Since it has been shown that the viscosity of a casein solution bears no constant relation to that of the coating mixture made from it, any tests designed to show the quality of the coating mixture should be made on the mixture itself.

Such tests may be made very conveniently and accurately by means of the MacMichael *viscometer*. This instrument is not seriously affected by small amounts of fairly coarse suspended matter in the mixture, and the effect of different temperatures can be studied on the same sample without removing it from the instrument. If this, or any other, commercial viscometer is obtained, full directions will come with it; but it is not necessary to purchase an instrument, as a homemade one can be constructed from materials found in any laboratory.

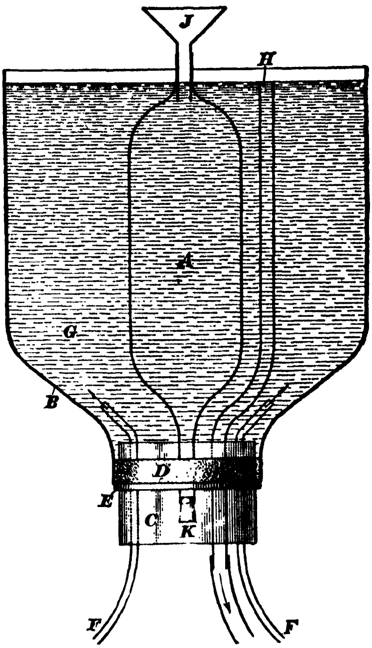


FIG. 3.

An instrument constructed by Norman Clark (one of the authors of this Section) from a 100-c.c. pipette, with a delivery tube not longer than 1 inch from the bulb, is shown diagrammatically in Fig. 3. A wide-mouthed bottle *B*, of clear glass, is inverted, after removing the bottom. A piece of glass tubing *C*, about 4 inches long, is inserted into the neck of the bottle and is made water-tight by the rubber band *E* and a cork *D*, which fits into the end of the tube. A pipette *A*, of 100-c.c. capacity, with a mark made on the outlet, near the bowl, and a graduation near the top, has its outlet projecting through the cork, which holds the pipette in place. Hot-water tubes *F*, *F* lead water *G* of constant temperature into the bottle; when the desired height is reached, the water overflows into the tube *H*, which

conducts it outside the bottle. A funnel J enables the pipette to be filled with the material to be tested, and a plug K fits the outlet of the pipette.

To use the instrument, first fill it with water of the temperature at which it is desired to test the casein solution or coating mixture, and have the water in the bottle at the same temperature. Allow the water to run out, and note the time required to empty the pipette. Repeat this several times in order to get an accurate average figure, and then go through the same performance with the solution or mixture whose viscosity it is desired to learn. This method gives the viscosity compared with that of water, a figure that may be compared with that of any other similar instrument.

GLUE AND OTHER ADHESIVES

49. Glue.—Glue is made by extracting various animal tissues with boiling water, concentrating the solution, and cooling this to form a jelly, which is then cut into sheets and dried under carefully controlled conditions. Commercially, glues are classified from the stock used in their preparation—hide, bone, or blended. Glues are sold in upward of twenty grades, based on considerations of jelly strength and viscosity. The best hide glues form the highest grades; the poorest bone glues, the lowest grades; the medium and high grades of bone glues overlap the low and medium grades of hide glues and, with the blended glues, occupy the middle zones of the grade scales.

Glue is now seldom used in the coating of paper, because it is more expensive than casein and gives a coating less resistant to water; but if it is desired to use it with the best results, a hide glue should be selected instead of a bone glue. For convenience in handling, ground glue is much to be preferred to flake or sheet glue.

In preparing glue for use, it should be soaked in cold water until all particles are thoroughly wet through; then heat may be applied until solution takes place. Long continued heating and too high a temperature are to be avoided, as they cause some loss in strength. A convenient strength of solution is 2 pounds of glue per gallon of water, and 0.75 per cent of sodium dichromate may be added as a preservative.

The chief tests that have a direct bearing on the use of glue in coating are those for adhesive strength, acidity, and grease. The test for adhesive strength should be performed as described for casein. The amount of acid may be determined by titration with standard alkali solution, using phenolphthalein as an indicator; or the degree of acidity may be found by measuring its pH value. A qualitative test, which has semi-quantitative features, may be made for grease by preparing a strong solution, coloring it deeply with methylene blue, and brushing out the solution on a sheet of paper. The presence of grease is indicated by 'fish-eyes,' and their number gives some idea of its amount.

There are no fixed standards for glue in the coating industry, and the best way to judge its quality is to compare the sample with one from a lot that has proved satisfactory.

50. Starch.—Starch is sometimes used as an adhesive in place of casein or glue. The ordinary commercial starches, such as corn, potato, tapioca, etc., cannot be used, because the solutions obtained on boiling with water are altogether too thick, and coating mixtures prepared from them must be enormously diluted in order to spread at all. The acid-converted starches—generally sold as 'thin boiling'—give thin solutions when cooked with as little as four parts of water; but the coating mixtures made with them are 'dead' and are lacking in flowing and spreading qualities. They are therefore out of the question.

Starches that find a limited application are those prepared by oxidizing action and sold as 'oxidized' or 'chlorinated' starches. These are much cheaper than casein or glue; also, they are clean, of good color, and are not subject to putrefactive decomposition, because non-nitrogenous. Their chief disadvantage is that the coating cannot be made waterproof; neither will it take quite as high a finish on calendering as when the same pigments are mixed with casein. Starch-coated papers do not, as a rule, give quite such bright printing effects as casein-coated papers, and it was formerly thought that they were more absorbent and required more ink. In view of recent work with starch, these statements would seem somewhat open to criticism.

Starches should be tested for strength, as with casein; but a still more important test is that for viscosity of the coating mix-

ture in which it is used. Very few starches possess the property of thinning a clay *slip* (suspension) as does casein. If this characteristic is lacking to too great an extent, the coating mixture will be thick, and it will either need much more water or else it will spread in such a way as to give many brush marks. The viscosity of a coating mixture made on the mill formula will at once show whether a starch will be satisfactory mechanically.

51. Gums.—Gums, such as gum arabic, tragacanth, copal, dammar, etc., are not used in making ordinary grades of coated papers, though they find a limited use in specialties. No general methods for testing can be given, and any examination to be of value must be based on the way the gums are used, and be designed to show the special properties desired.

52. Albumin.—In the preparation of some specialty papers, as gold-stamping and one-coat waterproofs, egg and blood albumin are still occasionally used. Both are purchased in granular form and, before use, may be dissolved in about six times their weight of water at not over 70° to 80°F.

MISCELLANEOUS MATERIALS

53. General.—A number of materials not previously mentioned are used to some extent in making book paper, and still more so in the manufacture of specialties and other grades of coated papers. Among these are waxes, oils, anti-foaming materials, waterproofing agents, shellac, wetting agents, etc. Because of the nature of the work performed by these and the special character of the products in which they are employed, much information regarding them is considered to be secret. The following notes, therefore, are of a general nature, and they contain only such information as is common knowledge.

Some of these miscellaneous materials may be analyzed by well-known methods, but such analyses seldom throw much light on their use in coatings. It is better to devise practical tests to show their value under special conditions of use, and such tests should duplicate as nearly as possible the methods of operation in the plant where the tests are being made.

54. Waxes.—These are used in friction- and flint-glazed papers and similar products, to enable the desired high gloss or

polish to be imparted by the friction calender or flint machine. The action of these machines is essentially that of burnishing or smoothing, and wax is needed to bring out the proper finish on the paper.

Waxes are introduced into the coating mixture in the form of emulsions. These may be prepared with the aid of soap, and added as such; or the soap may be formed by adding soda ash, or caustic soda, to a mixture containing the wax to be emulsified and a saponifiable fat or wax. There are also numerous methods of producing emulsions by means of special emulsifying agents, or by means of soaps formed from stearic or oleic acid and triethanolamine. All these have the same object, which is to keep the wax or fat so finely subdivided that it will mix with the rest of the coating mixture without separating in lumps or causing spots or 'eyes' in the coating. It is impossible to give a complete list of the waxes that have been proposed for use in coating, or of the methods for emulsifying them. Doubtless many of the new synthetic waxes could be used to good advantage, except for their high price. In the list and formulas that follow, only those waxes that have proved satisfactory by long experience are mentioned.

Carnauba wax: Melting point 83° to 86°C.; very hard; very complex chemically, chiefly myricyl cerotate; derived from carnauba palm leaves.

Beeswax: Melting point 62° to 70°C.; complex chemically, but mainly myricyl palmitate.

Japan wax: Melting point 47° to 56°C.; not a wax but a fat; chiefly tripalmitin; very readily and completely saponifiable.

Ceresin: Melting point 58°C.; a purified mineral or earth wax prepared from ozocerite.

Paraffin: Melting point 32° to 80°C., according to grade; a mineral wax obtained from petroleum.

Stearic acid: Melting point 69°C.; an acid obtained from many animal fats by saponification; forms white scaly crystals.

55. Wax Formulas.—From the numerous emulsions that have been used, the following have been selected as illustrative, but not by any means as covering the entire field.

1

Yellow beeswax	100 lb.
Brown borax soap	15 lb.
Water	100 gal.

2. Especially for flints

Beeswax	50 lb.
Borax	5 lb.
Soap solution (1 lb./gal.)	2 gal.
Water	100 gal.

3

Carnauba wax No. 2	120 lb.
Brown borax soap	15 lb.
Ammonia	2 qt.

The ammonia is added after the heat is shut off.

4

Stearic acid	18 lb.
Carnauba wax	70 lb.

Melt separately, mix, then add to 80 gal. water containing 40 oz. caustic soda, at boiling temperature.

5

Stearic acid	60 lb.
Ceresin wax	60 lb.
Caustic soda	2.5 lb.
Water	50 gal.

Boil 1 hr., add 2 qt. of ammonia, and dilute to 240 gal. with cold water.

6

Paraffin wax (m.p. 49°–52°C.)	80 lb.
Stearic acid	20 lb.
Water	80 gal.

Boil, add a solution of 3.8 lb. of anhydrous sodium carbonate, and dilute with 100 gal. water.

56. Shellac.—The two common grades of shellac on the market are orange and white. **Orange shellac** varies in color from lemon yellow to orange. **White shellac** is much lighter in color, and is made by bleaching the orange. If the lac dye is not removed in preparing the shellac, the product is known as **garnet shellac.** All three are used in coated specialties.

Shellac is often adulterated with common rosin, and if it contains over 5 per cent, it should not be accepted. If a clear, transparent top size, or varnish, is to be made from white shellac, it should be purchased on a wax-free specification.

Shellac may be prepared for use by cooking in a wooden vat, or even a barrel, equipped with an agitator, cover, and direct steam line. For the three grades, operations would be about as follows:

1. *Garnet.*—Heat 52 gal. of water, add 3 qt. of 26° ammonia, and then 50 lb. of garnet shellac. Boil 2 hr. with agitation and with the cover on.

2. *Orange.*—Heat 52 gal. of water, add 2 qt. of ammonia, and shut off steam; add 50 lb. of orange shellac, allow to stand for 15 min., and boil for 1½ hr. with agitation.

3. *White.*—Heat 48 gal. of water, add 40 lb. of white shellac and 2 lb. of borax; boil; add 1 qt. of ammonia, and continue heating until dissolved. This solution is usually milky in appearance.

57. Softeners and Foam Reducers.—A number of materials are used for these purposes, and some serve both as softeners and foam reducers. As **softeners** may be mentioned Turkey-red oil, vegetal (sulphonated tallow), glycerine, invert sugar, etc. The value of such materials is very hard to prove; probably the best way is to make very careful comparisons of papers with or without them over a considerable period of time.

Among materials used as **foam reducers** are fusel oil, butanol, gasoline, ether, turpentine, pine oil, and numerous proprietary preparations sold under trade names. Some here mentioned, as gasoline, ether, etc., involve serious fire risks; others have disagreeable odors, and none can be found that are effective under *all* conditions. It is difficult to judge of the efficiency of the agents from their use in the plant, because there would, at times, be no foam even if they were not used. To be certain of results, observations must be made over a considerable period.

A method for determining the foam-reducing power of such materials was described by H. E. Williams in *Industrial Engineering Chemistry* for April, 1926. This method is helpful in weeding out the useless samples and indicating what to try on a practical scale; but its results must be interpreted by comparison with plant operations, for materials that are found satisfactory in some plants give poor results in others.

58. Wetting Agents.—These are substances that promote penetration of liquids into other types of matter. They find some use in the coating industry as aids to the thorough wetting out of pigments, especially those which are normally somewhat hard to mix completely with water. In some cases, they also serve as dispersing agents, as in the case of sodium silicate with clay.

Many of the modern wetting agents are sulphonic acids or their derivatives, but there are also sulphates of the higher alcohols, pine oil (containing hydrogenated products), etc. For some purposes, silicates and butanol may be considered as wetting agents. Some act in both acid and alkaline solutions, as well as in the presence of hard water, while others are limited to either acid or alkaline conditions.

From their very nature, these substances aid the penetration of water into the body stock; in other words, to injure or destroy its sizing. For this reason, they must be used with care.

THE COATING MIXTURE

PREPARATION

59. Mixing Room.—The room in which the coating mixture is prepared is the assembling room of the plant. Here are mixed the proper quantities of mineral matters, adhesives, colors, etc., and from this point the mixture goes to the coating machines. Although the procedure varies somewhat in different plants, the order of addition of the materials most generally followed for white papers is: (*a*) clay, satin white, and other white mineral matters; (*b*) casein or other adhesive; (*c*) dyes or other coloring matters to produce tinted whites; (*d*) wax emulsions and froth reducers. For colored coatings, the coloring matters are generally added before the casein.

The equipment for carrying out these operations varies widely in different plants: it depends on the kinds of paper being made, as well as on the personal preference of the operator. Where most of the coating is of one grade, or of a few closely allied grades, the materials can be prepared in relatively large quantities, and can be drawn off from storage or mixing tanks in the amounts desired: in such cases, cookers, mixers, etc., may be of relatively large size. But in the specialty mill, where the papers are made in great variety and in relatively small quantities, the equipment is in small units, and much of it must be in duplicate in order to accommodate the rapid change of orders, which is often necessary.

While it cannot be said that any one arrangement of equipment is superior to all others, there seems to be a preference for the three-deck type, located just back of the coating machines. On the top floor are the dissolving tanks, or cookers, for the casein, starch, etc., and the mixing tanks for clay, satin white, and other pigments that are used in bulk. On the floor below are the mixers, in which the coating mixture is prepared from the materials weighed or measured from the tanks above; and below this are the strainers, which deliver the final mixture to the supply tanks of the coating machines, or to the cans in which they are sometimes trucked to the coaters. If a plant prefers to mix dry clay with the casein solution, instead of supplying it as a slurry, the tanks for preparing it are omitted from the upper

floor. This arrangement is essentially the same as shown in Fig. 1.

60. Coating Mixers.—The mixers used for preparing the coating mixtures should be of such a type that they give complete and rapid agitation without whipping in air. Some are built with double agitators, the arms rotating in opposite directions; while in others, the arms of the agitators pass between stationary bars that are fastened to the side of the tank. The mixers may be built of wood or iron; but wood is harder to keep clean and free from odor, and metal tanks are preferable. In most mills, tall tanks with rapidly moving agitators are preferred to the lower types.

In some plants, the mixing tanks have been replaced by pebble mills, with the idea of getting more thorough mixing and avoiding loss of materials from lumps that strain out. The claims have been made that the use of pebble mills enables less casein to be used, and that it improves the finish that can be obtained on the paper. Careful comparisons with the usual tank mixers have failed to confirm these claims. Pebble mills are difficult to keep clean and sweet when they handle casein-containing materials; and if a small amount of material remaining in them begins to putrefy, it is likely to start the bulk of the coating mixture spoiling and to cause trouble with weak coating, frothing, and bad odors. Some coating plants that installed pebble mills have discontinued their use, though others still employ them. The very fine grinding that they give is said to be essential in the production of 'cast coating,' which is mentioned later.

61. Strainers.—Before being sent to the coaters, the mixture must be strained, to remove foreign matter and lumps of material that have not been thoroughly worked out. Coarse matter is easily removed by a screen of relatively coarse perforated metal, through which the mixture flows rapidly and without the need for brushing or vibration. Following this coarse screening, it is customary to put the mixture through a much finer screen, to remove fine sand, dirt, etc. Wire cloths for this purpose range from 80 mesh to as fine as 325 mesh for special purposes.

Old-type strainers employed revolving brushes to assist the mixture in passing through the wire. These were followed by screens with eccentrically mounted motors to give a vibratory

motion, and by those which threw the mixture against a screen by centrifugal action. The latest type, and much the more successful, is that known as the *Universal strainer*, which gives a rapid vibratory motion in both vertical and horizontal direc-

FIG. 4.

tions. The motor is fully enclosed, and the basket is easily removed from the frame for cleaning. The straining cloth is held between flanges on the bottom side of the basket, and, if of 50 mesh, or finer, it is backed by an 8 × 8 in. mesh wire for support. This screen is especially to be recommended because

of the ease with which it may be cleaned; but it is also far more efficient than the old types as a screening device. This screen is shown in Fig. 4.

62. Pumps.—Various types of pumps are used to handle coating mixtures; the one most generally employed is the gear pump (a form of rotary pump), which consists of two gears enclosed in an appropriate casing. The inlet is at the bottom and the discharge at the top of the casing. Centrifugal pumps may be used for this work if they can be so placed that the color flows to them by gravity, making priming unnecessary. Plunger pumps are hard to keep in good operating condition, because of the wear caused by the mineral matter, and the likelihood that coarse particles may prevent the valves from seating properly.

63. Typical Coating Formulas.—It is difficult to select formulas for coating mixtures that are of general application, because of the variation in practice in different mills, and, even in the same mill, with the demands of certain customers. The method of finishing the paper also influences the proportion of casein required to hold the pigment to the paper. The proportions are approximately as shown in the following table:

Friction finish..........	6% to 10% dry casein to pigment
Plate finish.............	14% to 18% dry casein to pigment
Litho finish............	10% to 20% dry casein to pigment
Waterproof (ground coat)	15% to 25% dry casein to pigment

If these limitations are borne in mind, some idea of the make-up of various coating mixtures can be obtained from the formulas shown on p. 36, in which the casein solution contains 1¼ pounds of casein per gallon, and the emulsions 1 pound of wax per gallon.

It will be noted that where satin white is used, a larger amount of casein is required than where clay only is used. In general, the more finely divided the material the greater the proportion of adhesive required, because with a finer material more surface is exposed to be pasted.

64. Trying Color.—Coated papers are made of a standard color or to match samples supplied by the customers; and to accomplish this as rapidly as possible, some sort of color-matching procedure is essential. Where the same standard colors are being run every day, and especially if these are merely tints of white, experience indicates about what to use in the color formula;

and it is sufficient to take strips from the coated paper after the machine has started, calender them, and compare them with the standard to be matched. Corrections may then be made as desired.

BOOK PAPER

(1) 66 lb. dry clay
34 lb. dry satin white
11 gal. water
19½ gal. casein solution
Dyes for proper tint

(2) 100 lb. dry clay
8¼ gal. water
11½ gal. casein solution
Dyes for proper tint

FRICTION FINISH

(1) 100 lb. dry clay
2 lb. talc
5 gal. water
4 lb. dyestuff (4%)
6 gal. water
6½ gal. casein solution
6 gal. beeswax emulsion

(2) 300 lb. Turkey-red lake (33% dry)
2 lb. talc
1 qt. ammonia
7 gal. casein solution
5 gal. beeswax emulsion

PLATE FINISH

100 lb. dry clay
5 gal. water
4 lb. dyestuff (4%)
6 gal. water
10 gal. casein solution

LITHO FINISH

25 lb. dry clay
75 lb. dry blanc fixe
11 gal. water
Tinting
15 gal. casein solution

WATERPROOF

(1) Ground coat
300 lb. Turkey-red lake
1 qt. ammonia
20 gal. casein solution

(2) Top coat
1 gal. ammonia-cut casein (1 lb. per gallon)
1 gal. orange shellac
1 to 2 gal. water

When it is a matter of making many different colors, some of which are often new, it is very desirable to have a small-scale mixing equipment and some method of coating small sheets. A small laboratory coater is very useful for this work, but if one is not available, hand 'brush-outs' may be made. This method has the advantage of indicating to the experienced observer whether the mixture will probably brush out well on the machine; it also enables him to work out the color formula, indicates whether difficulties in mixing are likely to be encountered, and shows whether the paper can be made within the limit for cost. Such a system will not replace the testing at the coater when the order is started, but it will save much time and prevent many costly mistakes.

65. Process Chart.—The process chart, Fig. 5, represents the order of operations in a large mill. Not all mills have the ramifications represented in this chart, but the process for any particular plant can be laid out from it. A list of the principal

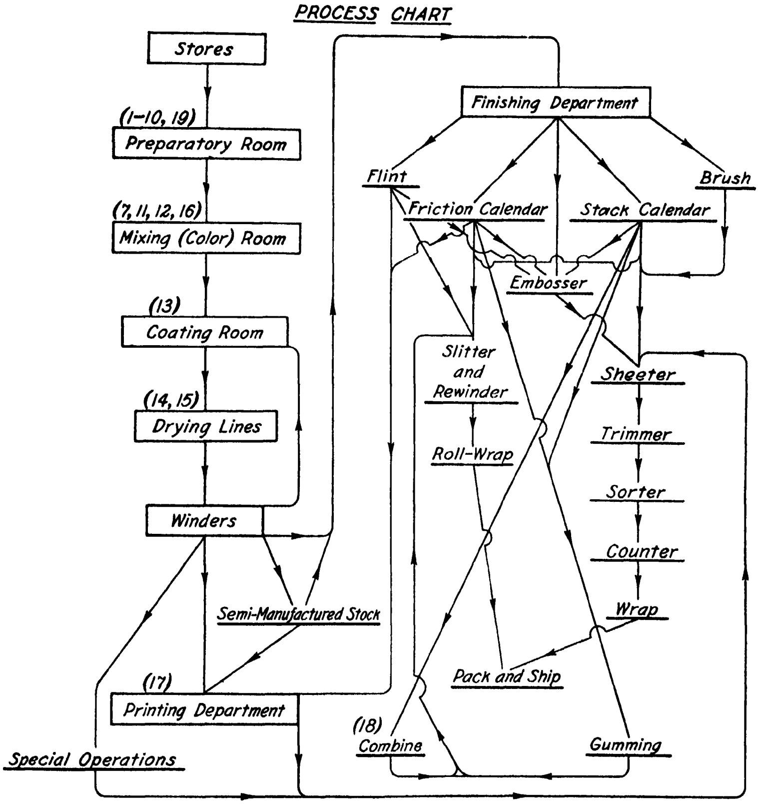


Fig. 5.—1, white pigments; 2, casein; 3, lake colors; 4, waxes; 5, shellacs; 6, gums; 7, water and steam; 8, alkalis; 9, glue; 10, starches; 11, metal powders; 12, acids; 13, paper; 14, heat; 15, air; 16, dyes; 17, inks (*a*, oil and varnish; *b*, cooked; *c*, aniline; *d*, casein); 18, adhesives (starches and flour); 19, colored pigments.

raw materials is given, and the point of entry into the process is noted by corresponding numbers.

APPLYING THE COATING

66. The Coating Operation.—The coating is usually performed as an operation entirely separate from the paper machine

on which the body stock is made; but in a few instances the paper machine and coater are tied up to run tandem, the full width of the paper being coated. This hookup has the disadvantage that anything that causes interruption of one part also puts the other out of production. Likewise, the paper machine usually runs faster than the coater, and it is more economical to operate the two as entirely independent machines. However, this does not apply to the modern 'machine coating,' which is mentioned later.

A number of different types of coaters take their names from the method of spreading the coating mixture or from some other operating peculiarity, as follows: (*a*) Brush coaters, which are of two general types—single coaters, or those which coat one side of the paper only, and double coaters, or those which coat both sides at one operation. Both types spread the coating by means of brushes. Single coaters may run in tandem, thus coating the two sides separately but in one operation. (*b*) Roll coaters, which are of the same two types as brush coaters, but the coating is applied by means of rolls, and brushes are either entirely absent or their number is reduced to a minimum. (*c*) Air-brush coaters, which use neither brushes nor rolls but spread the coating by a blast of air. (*d*) Machine coaters, which operate as a part of the paper machine, and act largely as roll-type coaters; they apply very thin coatings, hardly more than enough to fill the hollows between the fibers. (*e*) Cast coating, a coating applied by processes that serve some of the purposes of coating as well as calendering.

The classification of these different types of coaters is not hard and fast, since they overlap more or less, as when the coating is applied from a roll and is then spread by brushes. In the following descriptions of coaters, the classification is based largely on the method by which the coating is *spread* rather than how it is applied.

67. Brush Coaters: One Side.—The sequence of operations in coating one side of the paper is shown diagrammatically in Fig. 6. The paper leaves the roll *P* and passes under the cylinder *F* and between rolls *C* and *D*, the latter serving to keep the paper under tension and in close contact with *C*. The coating mixture is conveyed by roll *B* from pan *A* to roll *C*, and thence to the paper as it passes roll *D*. From here it passes under the brushes

E, over the suction apron *G*, and thence to the drying system, as indicated by the arrow *H*. The suction apron keeps the paper under tension and flat on the cylinder. The brushes *E* have a reciprocating motion, parallel to the axis of the cylinder *F*; this, combined with the forward motion of the paper, spreads the coating uniformly and smoothly over the paper.

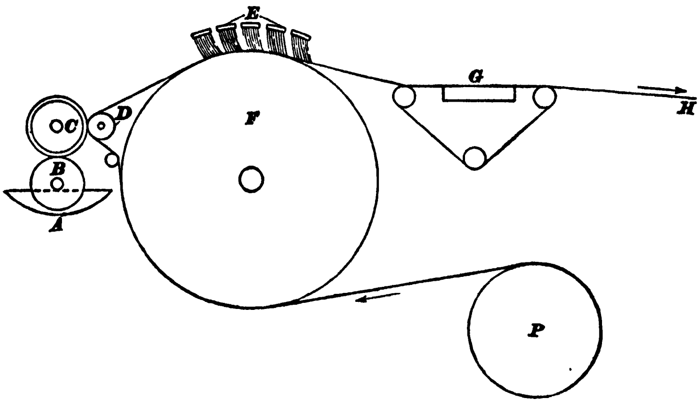


FIG. 6.

68. Other Types of Brush Coaters.—There are other types of **brush coaters** for coating one side besides the one just mentioned. The flat-bed machine carries the paper under the brushes on an endless rubber blanket. This is supported by a wood or slate table, over which it is caused to pass by two rollers, one before and one after the table. Flat-bed machines are either horizontal or inclined; and coaters are also constructed with an arched back, which is said to possess the advantages of both cylinder and flat-bed machines, without their disadvantages: *e.g.*, the flat face of the brush more closely fits the surface of the paper. One of the chief benefits derived from the cylinder, and also claimed for the arched-back machine, is that the paper will lie flatter and give less trouble with wavy edges than it will on the rubber apron of the flat-bed machine; this is especially true of very wide papers and those with slack edges. The cylinder machine is likewise better than the flat bed for heavy card stock, since sharp turns are avoided.

There are many methods of applying the coating mixture to the paper on single coaters, and some of the more common

devices are shown diagrammatically in Fig. 7, diagrams (*a*) to (*e*).

In diagram (*a*), the roller *R*, which is covered with a felt jacket, revolves in a box *B* and transfers the coating mixture directly to one side of the paper *P*, which is held against roll *R* by another roll *R′*.

Diagram (*b*) shows an endless-felt blanket *F*, which runs around two rollers *R* and *R′*, dips into the coating mixture, and

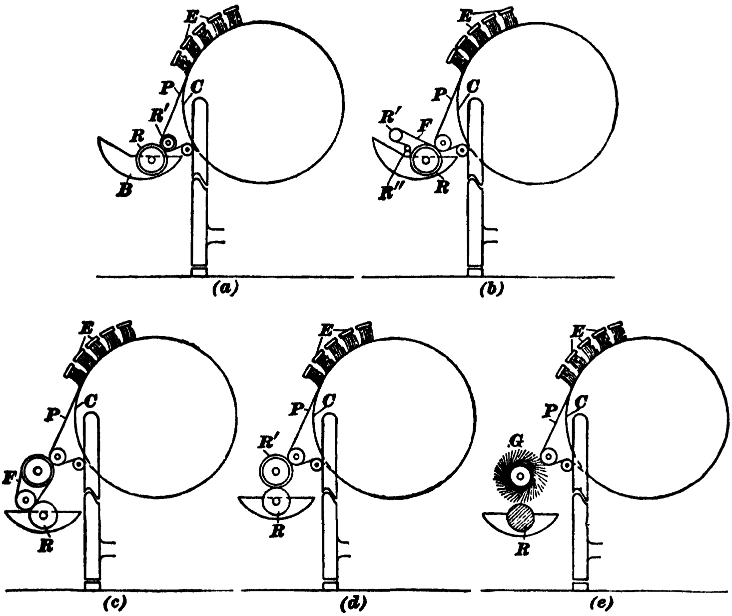


Fig. 7.

applies it to the paper *P*. A small third roll *R″* tightens the felt against the main roll *R*, in order to keep the coating mixture from working in behind the felt.

In diagram (*c*), an endless-felt blanket *F* takes the coating mixture from the roll *R*, which revolves in the coating mixture and applies it to the paper.

In diagram (*d*), the felt-covered roll *R′* receives the coating mixture from the roll *R* and then applies it to the paper.

Diagram (*e*) shows the use of a revolving brush *G*, in place of the felt-covered roll *R′* of diagram (*d*). This method is the one

used on most American coaters, while European manufacturers seem to prefer combinations of the felt rolls.

69. Brush Coaters: Two Sides.—A type of **double coater** that illustrates the principal feature of this apparatus is shown diagrammatically in Fig. 8. The paper passes from the roll *P* up over roll *F* and down under roll *B*, which is immersed in the coating mixture, but which is so arranged that it can be raised when threading the paper through the coater. From roll *B*, the paper passes between the squeeze rolls *D* and *D′* and thence

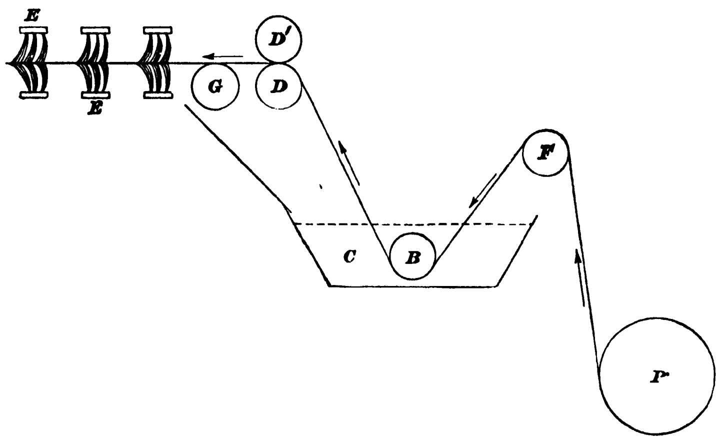


Fig. 8.

over the roll *G*, between the brushes and on to the drying system. The amount of coating applied is regulated by the pressure of *D′* and *D*, and this is controlled by screws at either end. The excess of coating mixture that is squeezed off falls back into the trough *C*. The squeeze rolls are rubber covered or else jacketed with felt. The rubber rolls are to be preferred, as the felt jacket tends to cause foam in the coating.

The arrangement just described allows the coating mixture to dry out locally in and around the trough, and permits the formation of lumps, which get onto the paper and cause considerable trouble. To get around this difficulty, the double coater shown in Fig. 9 has been developed. This has a much smaller trough *C*, which is located directly under roll *D*, so that the latter conveys the mixture to the under side of the paper. The roll *F*

is placed about on level with D', so that the paper dips down to the squeeze rolls, and the mixture is pumped, or allowed to flow, through pipe I and strainer S, onto the upper surface of the paper just before it enters the nip. The excess flows off the edges of the paper into the trough C below, where it serves as the supply for the under side of the paper. The paper passes over roll G and then between several pairs of brushes.

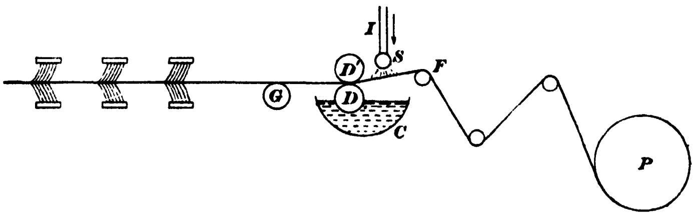


FIG. 9.

70. Roll Coaters.—The **roll coater,** so called because of the way in which the coating is applied and spread, has achieved great progress since about 1925. In most cases, these machines use no brushes, though in some cases the rolls are followed by one or two brushes. Some roll coaters

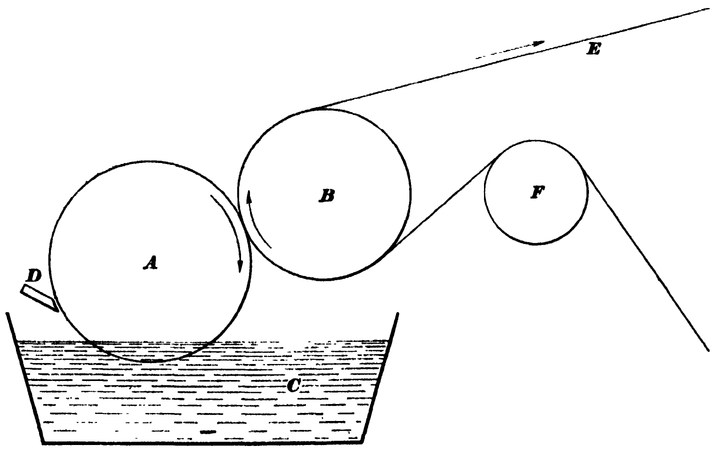


FIG. 10.

apply the coating on one side, while others apply it on both sides at one operation.

The simplest type of roll coater is shown in Fig. 10. Here the mixture is contained in pan C, in which roll A revolves and picks

up the mixture on its surface. A doctor at D, which is adjustable, removes the excess of coating. The paper E passes over the tension roll F, and then around roll B, which is in contact with roll A and revolves in the *same* direction; this causes the roll surfaces to revolve in *opposite* directions at the point of contact. The peripheral speed of roll A is two to three times that of B, thus tending to wipe off and smooth the coating surface. Roll B is of some elastic material, such as soft rubber.

This principle of applying or spreading (or both) the coating by means of rollers revolving against the direction of travel of the paper, and at considerably higher speed, is common to most of the roll coaters, but the mechanisms by which it is accomplished vary tremendously. In some, the coating mixture is applied simply as shown in Fig. 10; in others, it passes from roll to roll, to ensure even distribution, and is then applied to the paper. This method of distributing the coating mixture is the same in principle as that used on printing presses for ink distribution.

Coating both sides is accomplished in some cases by employing two coating units operating in tandem. After coating the first side, the paper passes a large drying cylinder, with the coated side away from it, and when sufficiently dry not to adhere, it goes to a bank of regular machine dryers and then to a second coating unit, which coats the other side. In another type of machine, one that coats both sides at once, the brushes above and below the paper are replaced by rollers, which may be run in either direction. While threading the paper through, the rolls are driven with the paper; but when applying the coating, they turn against the travel of the web. If only the upper side is to be coated, the rolls under the web of paper turn with it. On this type of machine, the rolls may oscillate, as do the brushes.

71. Air-Brush Coater.—The **air brush** is a device (patented) for spreading and smoothing the coating on the surface of a web of paper by means of a blast of air, and without the use of any of the customary brushes. The paper passes first between squeeze rolls; or over an *applicator roll*, which serves to apply the coating to one side of the paper and to regulate the amount to that desired, or slightly more. The web then passes the air

brush, which consists of a specially constructed chamber extending across the width of the web. This chamber is slotted and is adjustable, so that a jet of air may be caused to impinge on the paper at any desired angle. This air jet serves to force the coating mixture against the surface of the paper, and at the same time distribute it evenly and remove any excess over the desired weight. While this is taking place, the uncoated side of the web must be firmly supported by some smooth surface, as a roll or the like. After passing the air brush, the paper is conveyed to the drying line, to be dried in any of the customary ways.

This device will spread the coating equally well at any speed. Its upper speed limit is not known, since the construction of the machines and drying apparatus impose limits well below that of the air brush to spread the coating.

72. Machine Coating.—In the generally accepted sense, *machine coating* is not a regular coating process, since it was developed to apply a very thin coating, about a pound per side per 1000 sq. ft., with the object of filling the spaces between the fibers rather than to cover them entirely with a uniform surface. The name is derived from the fact that the process was developed for use on the paper machine, and it is usually carried out as an integral part of the papermaking operation.

The process is conducted in a number of different ways, of which the most general is by application of some sort of a roller coater located between sections of the bank of dryers, so that, when coated, the paper is still rather damp. Considerable pressure is used on the applying rolls, in order to drive the coating mixture into the depressions of the paper and anchor it firmly. Another device uses a wiper blade to remove practically all the coating above the level of the fibers. Some of these machines coat both sides at once, and some only one side; in the latter case, the web may pass to a second unit to coat the other side.

A different type of machine coater is that in which the dry coating ingredients, in finely divided and thoroughly mixed form, are dusted uniformly onto the paper web, while the latter contains enough moisture to react with the powder and form an effective coating. Application of the powder over the suction boxes at the wet end of the paper machine seems to be the

favored location, though it can also be applied at the presses, or even between sections of the dryers.

Machine-coated papers are superior to uncoated papers in printing qualities, color, and opacity, but are inferior to the usual heavily coated grades. The quality of machine coateds is improving with greater experience in manufacture, and they are replacing regular coated grades in many instances.

73. Cast Coating.—This method of coating paper is one that serves the purpose of both coater and calender. The coated paper is pressed against a solid surface while the coating is in a highly plastic condition, and when dried it takes on the finish of the surface it contacted. For instance, a sand-blasted surface on the dryer will give a dull-coated paper, while a highly polished surface will give to a clay coat a better finish than is obtained by ordinary methods, even when satin white is used.

For most coatings a steam-heated drum may be used, while materials that are plastic while hot may be water-cooled. The paper may be pressed onto the polished surface by tools acting on the other side of the sheet, and it is best to keep the paper in contact with them throughout most of the hardening operation. One of the requirements of the process is that the coating shall not stick to the surface against which it is dried. For starch and casein coatings, chromium, monel metal, or hard rubber may be used, or wax may be applied to metals to which the coating would normally adhere, as copper and steel.

This method is adaptable for light or heavy coats. The coating so made is free from 'mottle,' and is of high bulk and opacity. At present, the process is applicable only to papers coated on one side.

74. Patents on Coating Processes.—Many of the foregoing processes are patented, and care must be taken not to infringe on them. The following is a partial list of recent patents relating to methods of applying coating mixtures to paper. The classification into roll coaters, machine coating, etc., is more or less arbitrary.

Roll Coaters:

U. S. 1,597,218 J. Traquair	Aug. 24, 1926
U. S. 1,597,219 J. Traquair	Aug. 24, 1926
U. S. 1,774,398 L. A. Parker	Aug. 26, 1930
U. S. 1,847,065 C. Münch	Feb. 23, 1932

Roll Coaters:

U. S. 1,933,963	D. B. Bradner	Nov. 7, 1933
U. S. 1,936,286	D. B. Bradner	Nov. 21, 1933
U. S. 1,942,383	C. A. Dickhaut and C. C. Willis	Jan. 2, 1934
U. S. 1,989,036	D. B. Bradner	Jan. 22, 1935
U. S. 2,009,631	W. J. Montgomery	July 30, 1935

Air-Brush Coaters:

U. S. 1,980,923	S. Lebel (assigned to S. D. Warren Company)	Nov. 13, 1934

Cast Coating:

U. S. 1,719,166	D. B. Bradner	July 2, 1929

Machine Coating:

U. S. 1,707,333	J. Traquair	Apr. 2, 1929
U. S. 1,913,329	D. B. Bradner	June 6, 1933
U. S. 1,918,095	R. C. Germanson and F. Kranhold	July 11, 1933
U. S. 1,921,368	P. J. Massey	Aug. 8, 1933
U. S. 1,921,369	P. J. Massey	Aug. 8, 1933
U. S. 1,957,817	C. G. Bright	May 8, 1934
U. S. 2,030,483	D. D. Uong	Feb. 11, 1936
U. S. 2,044,281	J. d'A. Clark and J. Traquair	June 10, 1936
U. S. 2,053,601	O. E. Cheatham	Sept. 8, 1936
U. S. 2,062,563	A. E. H. Fair	Dec. 1, 1936
U. S. 2,079,846	A. E. H. Fair	May 11, 1937
Brit. 474,829	P. J. Massey	Nov. 1, 1937

75. Brushes.—The brushes used to spread the coating mixture will vary in number from 4 to 10 for single coaters, or 4 to 10 pairs for double coaters, according to the speed of the machine and the nature of the material applied. In general, the greater the speed and the heavier the coat the more brushes are required. The opinion has been expressed that for ordinary coating, a brush is required for approximately every 40 feet of speed; that is, 5 brushes for 200 feet per minute, 7 brushes for 280 feet, etc.

The brushes vary in quality, the stiffness of the bristles decreasing as the paper goes forward. The first brushes which the paper meets are known as *scrubbers* and are made of gray Russian bristles; the next brushes are called *blenders* and are made of black China bristles; the last are known as *finishers* and are made of badger hair. The cylinder brushes that are used to apply the coating to the paper are either all Russian or mixed Russian and China bristles.

Brushes have some rather serious faults, such as warping of the backs and shedding of bristles. Attempts have been made, but without entire success, to substitute metal backs for the wood

generally used, and thus to avoid warping. This trouble is not bad on narrow machines, but it becomes serious on the wider ones. Shedding of bristles may be caused by their becoming brittle and breaking off; or they may come out of the cement that holds them in the back. In either case, they are likely to cause cuts in the paper, and they may stick to the calender rolls and spoil much paper before they are discovered. Badger hairs are especially likely to become brittle, and this tendency may be still further enhanced by a strongly alkaline condition of the coating mixture.

The length of life of brushes depends on so many conditions that no very exact statement can be made. Badger-hair brushes will probably not last over six months if used continuously, while the others will last a year, and often much longer. All brushes will last longer on single than on double machines. The care —washing, drying, and trimming—given them influences their length of usefulness very considerably. All brushes should be washed at least once in 8 hours: a washing machine is very desirable, as it is more thorough than hand washing, and the centrifugal action tends to throw out any loose or broken bristles, and the bristles are kept straighter. The washing and drying are so much quicker with a machine that they may be done oftener.

The amount of pressure that the brushes exert on the paper and the length of throw of the brushes are two of the chief factors in spreading the coating satisfactorily. Neither of these can be described very well in writing, and the effect of different conditions must be learned by observation and experience.

DRYING AND FINISHING OPERATIONS

DRYING SYSTEMS

76. General Methods of Drying Single-Coated Paper.—There are two general methods of handling single-coated paper on the dryer; the first is the festoon-type system; the second is known as the straight-pass system.

In the **festoon system,** the paper is looped over a series of sticks, which are carried along on a horizontal chain; the loops are called **festoons.** The festoon dryer may be either of the straight-line type or of the return-line type. In the **straight-line type,**

the chain carrying the sticks is arranged in a continuous straight line, the coater being at one end of the line and the winder at the other end. In the **return-line system,** there is a section of straight chain from the coater, at the other end of which is a turn-around mechanism, and then a return chain leading back to the winder alongside the coater.

The second type of dryer for single-coated paper, the **straight pass,** is so arranged that the sheet travels from the coater, without being looped, direct to the winder. The path of the paper between the coater and the reel may be horizontal or it may be arched. Where the paper is of such a character that it will not curl excessively, the horizontal straight pass is suitable; but where there is a strong tendency to curl, the *arch type* should be used. There are installations having a combination straight-pass and festoon dryer, the sheet being carried along a straight-pass section and later hung up in festoons. It is claimed that a combination system of this type would permit the sheet to straighten out by reason of its moisture absorption, before being looped, and thus would eliminate to a large extent wrinkles or marks that might originate at the sticks.

77. Double-Coated Paper.—There are two methods of handling double-coated paper: the first is known as the **floater and festoon;** the second, as the **floater and straight pass.** By the first method, the sheet, after leaving the coater, is supported by means of air jets for a distance sufficient to dry the under side of the sheet to such an extent that it can be hung in festoons without scratching the under side. By the second method, the festoon rack in back of the floater is replaced with a straight pass.

The most common arrangements for drying are the straight-line festoon system, the return-line festoon system, both for single-coated paper, and a combination of floater and festoon for double-coated paper. These will now be described in greater detail. The straight-pass types are comparatively new in development, and are being used to avoid the speed limitation of the festoon racks: they require, however, higher temperature for drying.

78. Straight-Line Festoon System.—A system of this type is shown diagrammatically in Fig. 11. Here A is the coating machine; B is the uptake rack to carry the paper to the line; C is

the drying line, the chains carrying the sticks at four different speeds; D is the rack to carry the paper from the line to the reel; E is the stick box, into which the sticks drop, and from which

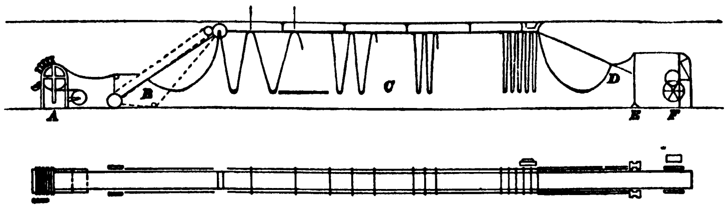


FIG. 11.

they are automatically returned to the other end to be used over again; F is the reel.

Some of the details of the drying equipment are shown in Fig. 12, which is a reproduced photograph. The chain C, which has

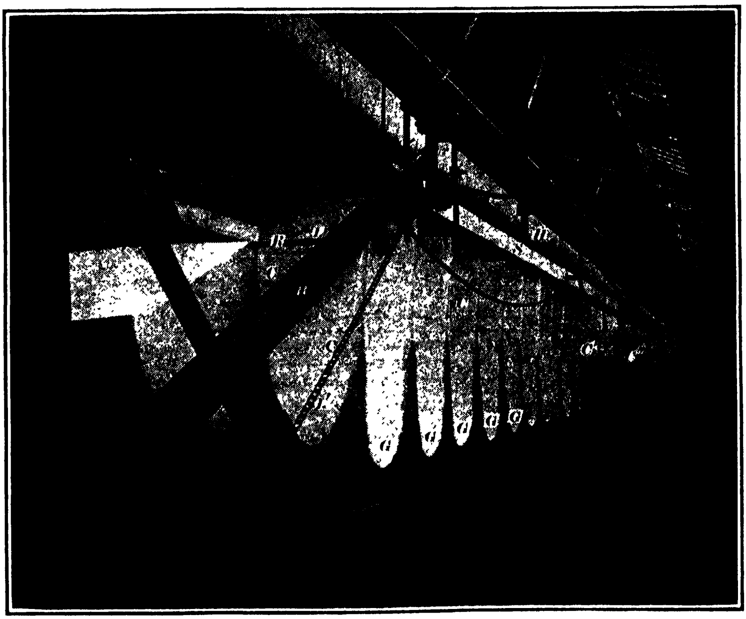


FIG. 12.

two lugs L and L', picks up the stick R and carries it to the inclined rail P. The stick is taken automatically from a trough below the paper, and as it is carried up, it takes the paper along with it

in the form of a loop or festoon. At the upper end of the incline the sticks are deposited on a chain C', running along the horizontal track S. This chain does not run the entire length of the line, but is succeeded by other chains C'', C''', etc., each traveling at a lower speed than the preceding one, so that the distance between the sticks supporting the paper decreases with each chain as the paper passes along toward the reel. Thus the loops are very close together at the end next the reel, where the paper is quite dry.

The heated air for drying the paper is delivered through a system of duct work located above the festoons. The air is blown downward through the loops, and is removed through openings in the floor. Some of the air is exhausted, and the remainder is returned to the heating apparatus for recirculation. A few of the very old lines had steam pipes laid on the floor under the loops, without any air circulation; but this method has been practically abandoned, owing to the slow rate of drying and the overdried bottoms and edge of the loops.

With a straight-line festoon system, the building enclosing the rack is comparatively long, since these lines are 200 to 400 ft. in length. It is easier, however, to control the drying along the straight rack, by reason of the gradual changing from the wet to the dry condition.

79. Return-Line Festoon System.—The return-line system is shown in plan in Fig. 13, in which the letters A, B, and C have

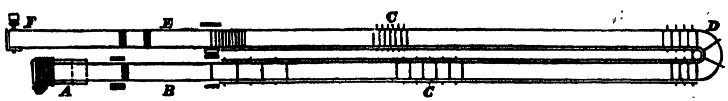


FIG. 13.

the same meaning as in Fig. 11. The turn-around D consists of a flat disk, which supports the inner ends of the sticks, while the outer ends are carried around the half circle by means of an endless chain running on sprockets. The outer ends of the sticks are frequently a little higher than the inner ends; this causes the sticks to slide in toward the center of the half circle and prevents them from falling off the disk. The rack E carries the paper from the line to the reel F.

The return-line system has two great advantages over the straight-line. First, the building need be only approximately

half the length required for the straight-line system; second, because the coater and winder are practically alongside each other, the operator in charge can see the finished product as he is coating, and he can make any necessary adjustments in the coating or drying. However, with the turn-around arrangement, the wet line is close to and parallel to the dry line, and it is more difficult to control the drying, unless a dividing partition is installed between the two lines.

80. Drying Double-Coated Paper.—The drying of double-coated paper is complicated by the fact that it cannot be looped on sticks until the coating on the under side is dry enough to keep it from being scratched by contact with the sticks. To effect this partial drying, as soon as the paper leaves the coating machine, it is carried over an arrangement known as a **floater.** This consists of a large air duct, parallel with the course of the paper and directly under the web, having slots running across it on the upper surface. Heated air is blown into this duct and emerges through the slots against the under side of the wet, coated paper, which is thus supported without coming into contact with anything except the air. Each slot is supplied with a deflector, which directs the air against the paper in the direction the web travels, instead of vertically. Between the floater and the loop line is a suction apron, against which the paper is held, and which pulls the paper over the floater to deliver it to the sticks of the drying line. Beyond this point, the equipment is the same as for single-coated paper.

Floaters vary greatly in different plants; they may be anywhere from 70 ft. to 140 ft. long, and of a width corresponding to that of the paper to be coated. They are sometimes, but not generally, separated from the coater at one end and the loop line at the other end by partitions, through which the paper passes by means of narrow openings. The temperature of the air emerging from the floater slots varies from about 150°F. to approximately 250°F., depending on the weight of coating applied, the length of the floater, and the speed at which the sheet is coated.

81. The Drying Problem.—The object of drying is to produce a sheet that is uniformly dried across its width and along its length. Enough moisture must be left in the paper to produce

the maximum finish with the least weighting on the calenders: at the same time, the sheet should not be so wet as to cause blackening in the calenders.

There are several opposing viewpoints and methods regarding the operation of coated-paper dryers; these may be described as follows:

(*a*) *Low-Temperature vs. High-Temperature Drying.*—Arbitrarily, the dividing line between low and high temperature is often considered to be 220°F. Practically all of the festoon type of drying systems operate in the low-temperature range, the maintained temperature varying from 90°F. to approximately 150°F. With a straight-pass type of dryer, where there is little time for drying, it is necessary to go to a high temperature, often to 300°F. and higher. When drying at such a high temperature, the final drying point is very critical, and the finished sheet is likely to be overdried.

Any imperfections of the coating would also become apparent, because of the critical drying conditions. With the low-temperature method of drying, it is much easier to control the final moisture content of the sheet, and it is claimed that the finish and bond qualities are better than when high temperatures are used.

(*b*) *Controlled Drying vs. Re-humidifying.*—On some of the festoon drying racks, the sheet is dried down more than is required, in which case, it is allowed to pass through a section having a high humidity: this high-humidity chamber returns to the sheet the desired amount of moisture. Another method of arriving at the correct moisture content is actually to control the drying, so that the sheet is not overdried. This is done by means of temperature- and humidity-control equipment that regulates the amount of steam to the heaters and the amount of air exhausted.

82. Speed of Coating Machines.—The speed of a festoon coating line is generally limited to the rate at which the paper can be removed from the festoon rack. As a rule, the capacity for drying and the potential speed of the coater are above the mechanical speed limitations of the festoon rack. With a straight-pass type of dryer, the limitations are all on the drying systems, since it is practical to coat, to wind, and to handle the

paper on the straight-pass conveyor at comparatively high speeds. The speed of double-coated paper is limited by the length of the floater, whether it be a floater and festoon combination or a floater and straight-pass combination. Here, again, the limitation is placed on the drying system, and high temperatures and large volumes of air must be used. If the double-coated sheet at the end of the floater is not sufficiently dried on the under side, that side will be scratched as it passes over the suction apron, and the speed would have to be cut down to correct this condition.

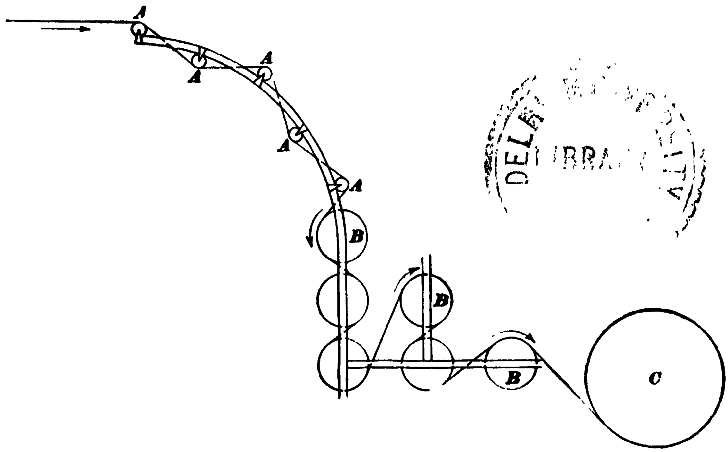


Fig. 14.

83. Reeling the Paper.—At the end of the drying line is the reeling equipment, which takes the paper from the line and winds it into a roll, ready for the finishing operations. A diagrammatic illustration of one type of reel is given in Fig. 14. The rolls or bars *A* smooth out the paper, and the rolls *B* act as a brake, to put sufficient tension on the paper to secure a tightly wound roll at *C*. This type of winder is used in about half of the coating mills, while the rest use some make of the ordinary drum winder, which is common throughout the paper industry. Both types are fully described in previous Sections of this volume.

Color edge, or the presence of coating on the uncoated side of the paper, may give trouble in winding, especially with a drum winder. This edge is sometimes trimmed off before winding.

FINISHING OPERATIONS

84. Equipment.—The finishing room in a coating mill making book papers includes supercalenders, cutters, trimmers, etc., as described in the Section on *Paper Finishing*, to which reference should be made. Other types of coated paper, however, utilize special finishing machinery, such as the friction calender, which gives a very high finish to one side of the so-called 'frictions,' used largely for box coverings. This and the embossing machine, which is used principally for producing a design or trade-mark on many kinds of paper, will also be found described in the Section on *Paper Finishing*.

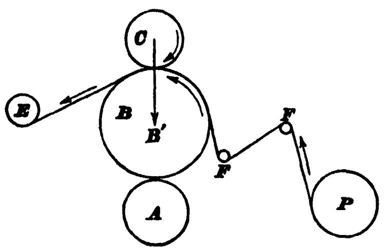


FIG. 15.

The only appreciable difference between supercalendering plain and coated papers is in the type of calender rolls used. For plain papers, paper-filled rolls are employed, while those for coated papers are cotton filled, and are not so hard as the paper rolls. Cotton rolls are made of varying hardness, to suit the preference of different plant managers.

85. Friction Calender.—The friction calender is illustrated diagrammatically in Fig. 15. A chilled cast-iron roll A drives the **paper bowl** (roll) B; C is a highly polished chilled-iron roll; P is the roll of paper to be frictioned; E is the rewound roll of finished paper; F, F are idler rolls.

The paper is led over the first idler roll and under the second and then passes between the paper bowl B and the highly polished chilled-iron roll C, and thence to the winder. The coated side of the paper is next to the chilled-iron roll C, whose peripheral speed is from $1\frac{1}{2}$ to 4 times the speed of the paper bowl B; this causes roll C to produce a friction or ironing effect on the coated side of the paper, and makes it very smooth. The diameter of roll C is usually about one-third of the diameter of the paper bowl; and it is piped in such a manner as to allow the admission of either cooling water or steam, as conditions may require. The paper bowl usually travels at 70 to 100 r.p.m.

Experience has shown that chromium-plated rolls for frictioning, in place of the chilled-iron roll, are not satisfactory. It is believed that the minutely porous surface of the chilled iron is essential for good results.

86. Brush Machine.—Coated paper containing much satin white is sometimes finished by subjecting it to the action of rapidly revolving brushes, after which it is passed through the supercalenders. This gives a very attractive, velvety, or suede finish, which is much desired for printing illustrations of various kinds, making cigar bands, etc.

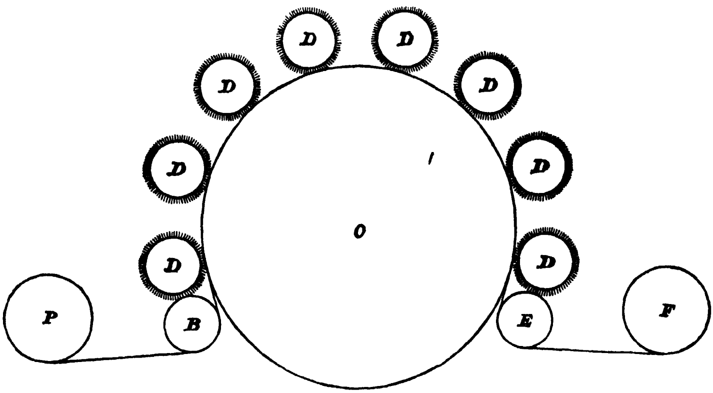


FIG. 16.

A diagrammatic sketch of a brushing machine is given in Fig. 16. Here *P* is the roll of paper to be brushed; *B* is an idler roll, to bring the paper against the cylinder *C*; *D*, *D*, etc., are the revolving brushes; *E* is another idler roll; and *F* is the roll of brushed paper. The surface speed of the brushes is usually about 6 times that of the paper. The brushes vary in hardness, the bristles gradually increasing in stiffness as the paper travels from roll *B* to roll *E*.

87. Flint Glazing.—**Flint glazing** is probably the oldest method of producing a highly glazed paper; it is still the system by which the highest finishes are obtained, except, possibly, in the case of cast coating. The paper travels ahead very slowly, passing over a smooth, flat, wood surface; a flint stone is drawn back and forth over the paper, pressing it against the wood surface and

imparting a very high finish to the side of the paper touched by the flint. This method is extremely slow, since the average production per machine per day is only about 2½ reams. To secure quantity production, it is necessary that a mill have a large number of these machines. However, a single operator can watch about ten of them.

A flint machine is illustrated diagrammatically in Fig. 17, the operation of which is as follows: *L* is a driving gear that turns roll *K*, which unwinds the paper to be finished from roll *A*; the paper forms a loop, which is held taut by the idler roll *B*, which rests in, and is supported by, the loop of paper; the paper passes over roll *M*, over the flat, smooth holly or pearwood board *D*, over roll *N*,

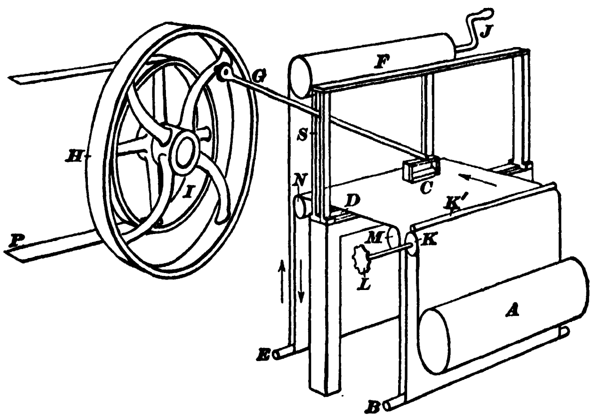


FIG. 17.

and forms another loop, in which rests the idler roll *E*; thence, the paper passes to roll *F*, where it is wound up by turning the handle *J*. The flint *C* is drawn back and forth across the paper by the link *G*, the other end of which is attached by a pin to an arm of the wheel *H*, driven by the pulley *I*, which, in turn, is driven by the belt *P*. The roll *K'* nips the paper as it passes over the roll *K*. Before starting up the machine, the paper is passed loosely over the rolls *K*, *M*, *N*, and up over roll *F*; the rods, or idler rolls, *B* and *E* are dropped into place, and thereby form loops of little depth and tighten the paper. When the machine is put into operation, the turning of roll *K* unwinds the paper from roll *A* very slowly; roll *F* is stationary, and the slack is taken up by the weight of the idler roll *E*, which keeps the paper

stretched tight across the board *D* and increases the depth of the loop, *E* moving slowly downward. When roll *E* has descended so far as nearly to touch the floor, the operator turns the handle *J* and winds up the paper until the roll is raised to its initial position. In the meantime, the stone (flint) *C* is being drawn back and forth across the paper with sufficient speed to cover every part of the surface of the paper.

88. Equipment Chart.—The equipment of the coating plant is summarized in the following chart, Fig. 18. For convenience

EQUIPMENT CHART

Preparatory room	Bins (for clay or other pigment) Mixers (wooden, 100–800 gal.) Kettles (jacketed iron) Containers for lakes Pony mixer Measures, scales, pails, dishes, etc. Strainers, trucks
Mixing (color) room	Mixers (wooden, 250 gal.) Strainers, tubs, measures, pails, dippers, etc. Scales Trucks
Dyestuff (aniline) room	Kettles (jacketed copper) Scales Racks, dippers, bottles, etc.
Coating room	Coating machines Reels Small machine mixers Brush washer Dry-line equipment
Finishing department	Stack and friction calenders Flint and embossing machines Sheeter and trimmer sorting tables Slitter and winder
Ink room	Grinders and mixers Kettles (jacketed copper) Strainer (mechanical) Scales, measures, and containers
Printing room	Intaglio press Surface printer Wallpaper machine Embosser—printer

FIG. 18.

in visualization, the equipment is arranged (grouped) by operating rooms. No attempt has been made to go into detail, and

the list is given to classify the various rooms in the coating plant by the machines, apparatus, etc., they contain.

89. Sorting, Packing, and Storing.—The general discussion of these subjects in the Section on *Paper Finishing* also applies to coated papers, but these should be handled with even more care than other papers. On the part of the sorter, constant vigilance is necessary, because coated papers may possess defects that ordinary papers do not have. There are brush marks to be looked for, and also skipped coating, and spots of various kinds that were not originally in the paper. Besides all these, foreign material is liable to get on the paper from the coating mixture or in the drying line while the paper is still wet. While looking for all these defects, the paper must be handled with considerable care, for the coating is comparatively brittle, and careless handling will result in cracked sheets.

The storing of coated paper requires especial care, since the adhesive is usually of a nitrogenous nature; it is therefore subject to decay and to the attacks of insects when stored in warm, damp places. This feature also necessitates great care in packing, when the shipment is to undergo a prolonged sea voyage.

The conditioning of air in finishing and storage rooms in paper mills is receiving more and more attention, as it is in the printing trades.

SECTION 4

COATED PAPERS

(PART 2)

GUMMED PAPERS

By GARDNER R. ALDEN

USE AND TESTING OF RAW MATERIALS

90. History and Use.—One of the earliest records of the use of **gummed paper** is that referring to postage stamps. In 1837, Sir Roland Hill brought to the attention of the English Post Office authorities the adhesive-stamp invention of Chalmers, a Scotchman. Since that time, its use has grown to tremendous proportions, particularly wherever greater convenience is desired in attaching paper quickly to various materials.

One of its principal uses at the present time is for sealing tape, particularly in the form of gummed kraft. Large quantities of gummed paper also are consumed in the manufacture of labels and seals. Other miscellaneous applications include its use for transparent mending tape, reinforcing tapes, index tabs, stamp hinges, passe partout binding, and stamps of various sorts.

Gummed cloth is closely related to gummed paper, but it will not be discussed here. The principal underlying methods of manufacture are similar to those described in this Section.

91. Types of Gummings.—Gummings of the water-soluble type, activated by remoistening, constitute the largest group; hence, the discussion of manufacture will be confined to this class. Water is the universal moistening agent. In some cases it is supplemented by the addition of chemical reagents, *viz.*, acids, alkalis, and glycerine, to improve adhesion.

Recently, however, certain kinds of water-insoluble gummings have been produced. Among other things, these new gummings

have been developed to meet the occasional requirement for better adhesion to resistant surfaces encountered in various modern packaging materials and to new types of lacquered and metalized finishes. They are composed largely of resinous materials, either of natural or synthetic origin. Some are designed to be remoistened with suitable organic solvents; others are activated by heat, that is, they are thermoadhesive or *heat sealing*. The latter type not only have a wide range of adhesion but may also be suggested where it is impractical to use solvents, or when instantaneous adhesion is desired. Because of their unique characteristics, heat-sealing gummings are becoming increasingly important.

Another class, which may be termed *pressure gummings*, are composed largely of plasticized rubber or rubber-like materials. They have a natural stickiness or 'tack,' which makes it possible to secure adhesion merely by pressure. They are limited at present to highly specialized uses.

92. General Considerations.—The desirable qualities sought in the manufacture of gummed paper are:

(1) A flat, or non-curling, paper.
(2) Quickness of stick, or 'quick-tack,' as it is called.
(3) Permanency of adhesion.
(4) Agreeable odor and taste.
(5) Non-blocking, or non-caking (*i.e.*, freedom from sticking together under humid weather conditions).
(6) Good printing qualities.
(7) Good writing surface.
(8) Adequate strength.
(9) Good appearance.

Some of these qualities become of greater or less importance according to the product; for instance, the feature of curling assumes greater importance in paper to be sold for printing purposes than for use as adhesive tape.

The gumming is applied in various amounts, depending upon the requirement, and ranges from approximately 10 lb. per ream to 30 lb. per ream 25 × 40—500. Heavy coats are necessary where application is to be made to rough materials, such as coarse fabrics.

RAW MATERIALS

There are two principal raw materials used—paper and adhesive.

93. Paper.—A wide range of papers is employed. Kraft paper, in weights of 35 to 100 lb., 24 × 36—480, is one of the most important papers because of the large quantity that is used. Other papers employed are principally of the book-paper class, and they vary in weight from approximately 36 to 70 lb. per ream, 25 × 40—500. Heavier weights, including tag-stock grades, are sometimes gummed for special purposes. The following represent types of paper generally used: white papers—sulphite, soda sulphite, rag sulphite, bleached kraft, and esparto; colored woves or mediums of the sulphite or sulphite-soda type; coated papers—white and colored; plated and glazed; gold- and silver-bronzed papers, metal-foil papers, and glassines. These papers may be either machine-finished or supercalendered as desired. Recently, transparent-sheet materials, of the regenerated-cellulose or cellulose-derivative type, have been gummed successfully.

94. Adhesives.—The kind of adhesive is determined by the particular requirement to be met. It is selected usually from two principal groups; namely, animal glues and dextrines. Fish glue and gum arabic are sometimes used, but these appear to be of minor importance at the present time.

95. Animal Glue.—This is, perhaps, the most important adhesive used in the industry; it appears on the market in a variety of grades, ranging from a low-grade bone to a medium-grade hide glue. These glues are obtained essentially from the skin, tendons, and bones of beeves and calves. The method of extraction most commonly used is to allow the stock first to swell by soaking in lime water for a few weeks, washing to remove the excessive lime, and then to heat in water. The higher grade glues are produced as a result of just a few hours' heating at low temperatures (158° to 176°F.), while succeeding runs are made by adding fresh quantities of water and using higher temperatures to produce the correspondingly lower grades. The glue is usually purchased by the gummer in the ground form, which makes it much more convenient to dissolve.

The outstanding features of animal-glue gummings are quickness of stick, high bonding strength, and resistance to blocking or caking under humid conditions. It is widely used for sealing tapes and for label purposes.

96. Dextrine.—Dextrine is sometimes considered as an intermediate product between starch and dextrose. It is derived from starch by a chemical process, usually by heating the dry starch to a temperature of 250°F. or more after the starch has first been moistened with dilute acid. A range of dextrines with widely different properties of color, solubility, brittleness, viscosity, and quickness of stick can be produced by varying the kind and amount of acid and the conditions of temperature and time used in the process of conversion.

Dextrine made from tapioca starch is generally preferred for gumming purposes in this country, chiefly because of its light color, cleanliness, uniformity, and excellent remoistening qualities. Corn and potato dextrines, while not so popular for gummed-paper use, are well known, and are very widely employed for adhesive purposes.

Tapioca dextrine gumming is excellent for general use on paper, glass, and other smooth surfaces, and where good odor and taste are desired. It can be made with excellent quickness of stick and satisfactory resistance to blocking under humid conditions. It is readily soluble in water, and a reasonable amount of care should therefore be used in remoistening.

97. Fish Glue.—Fish glue is of decreasing importance as an adhesive for gummed paper, although it has long held an excellent reputation among gummed-paper users. Most of the fish glue is made from the waste products of the cod, cusk, haddock, hake, and pollock industries. The head, skin, and trimmings are all used; but the skins of the cod and cusk are kept separate, as the glue made from them is of higher quality than that made from the other stock. The process of manufacture includes a preliminary step of washing the stock to obtain a low percentage of salt content, usually for a period of ten hours or more; this is followed by two or more runs of slow cookings in water to extract the glue. These dilute (about 5%) glue liquors are concentrated in suitable evaporators to a solid content of approximately 50%. Fish glues of good quality have a jelling point of about $7\frac{1}{2}$°C.,

and usually contain not more than two-tenths of one per cent of sodium chloride. Fish-glue gumming is characterized by a somewhat less rapid 'tack' and a greater tendency to block in humid weather than good grades of animal or dextrine gummings. It does have the quality, however, of providing a longer working period, after remoistening, and for certain uses this is a desirable feature.

98. Incidental Materials.—Essential oils, such as wintergreen, sassafras, etc., are used for flavoring, while glycerine, sulphonated oil, and glucose are sometimes added in small quantities to the gumming formula to improve its working characteristics and utility. The use of mineral fillers is very rare.

TESTING RAW MATERIALS

Tests are directed to the requirement of the manufacturing process, as well as to that of the finished paper for the consumer's use.

99. Paper.—In general, it should be kept in mind that gumming paper should have a good writing and printing surface, smoothness, freedom from dirt, and should not be unduly absorbent—on account of the requirements of the gumming process. A well-sized sheet will require much less glue than a poorly sized, absorbent sheet.

The tests most commonly employed are those which determine the tensile, folding, and tearing strengths, stiffness, weight, thickness, color, formation, dirt, absorbency, and writing surface. Methods for evaluating paper in accordance with these tests are given in detail in *Paper Testing*, Section 5.

100. Animal and Fish Glues.—The ability of an animal glue to run well on the gumming machine, and to produce a gummed sheet having good adhesive qualities, quick stick, and freedom from undue curling tendencies, may be predicted from a study of its viscosity and jelly-strength properties. The characteristic change in viscosity of a given glue solution with change in temperature can be found. However, for routine control, it is sufficient to determine viscosity at some one temperature point, this point to be selected in accordance with the grade of glue and the concentration used. For example, a good grade of bone glue may be tested at a concentration of 25% at 140°F.

101. Viscosity.—Both viscosity and jelly strength are determined by standard methods derived from those promulgated by the National Association of Glue Manufacturers. *Viscosity* is measured by the time of outflow of a predetermined quantity of glue solution, at a given concentration and temperature, from a standard calibrated glass pipette (viscometer). To get an accurate result, extreme care must be taken in the preparation of the glue solution and in maintaining exact temperature conditions. Viscosity is expressed in millipoises,[1] calculated from the time of outflow in seconds and the density of the glue solution.

Let V = absolute viscosity in millipoises;
D = density;
t = time in seconds;
A and B = pipette constants.
Then,

$$\frac{V}{D} = At - \frac{B}{t}$$

102. Jelly strength is determined by measuring the consistency of a glue jelly that has been carefully prepared by chilling a glue solution of proper concentration at a temperature of approximately 50°F. An instrument known as the *Bloom gelometer* is used to make absolute jelly-strength determinations. Essentially, it furnishes means for applying a varying load from a standard plunger placed in contact with the glue jelly. The result is expressed in grams required to produce a 4-mm. depression in the jelly.

The **finger test** for jelly strength should be mentioned here, because it is one of the oldest, most popular, and simplest of operations. While it lacks the quantitative accuracy of the instrument method just mentioned, it does serve practical purposes on occasion. The glue-jelly specimen is prepared in much the same manner as for the instrument test, and is of such a strength that, when chilled, the consistency will not be too high. In a similar manner, and at the same time, glue jellies are prepared from standard samples of glue of known jelly strength. In making the test, the fingers (or one finger) are pressed lightly

[1] One-thousandth of a poise. If the tangential force per unit area, exerted by a layer of fluid upon one adjacent is one dyne for a space rate of variation of the tangential velocity of unity, the viscosity is 1 *poise*.

upon the surface of the glue being tested, and the resistance of the jelly is compared with that of the nearest standard jelly.

103. Other Tests.—*Hygroscopic qualities*, which measure the tendency of a gummed paper to *block*, are determined by exposing samples of gummed paper to a range of controlled relative humidities and observing their behavior when packed together under light pressure.

Odor, *grease*, *taste*, *color*, and *foam* are observed and compared with a standard specimen. The foaming test is important, as any undue tendency in this respect will cause trouble during the gumming operation.

Quickness of stick may be measured by moistening ½-inch gummed strips, and comparing the rapidity with which they adhere to a standard paper surface with that of a gumming of a known quick-tack value.

For some purposes, it is important to know the *hydrogen-ion concentration* (expressed as pH) particularly where it is desired to avoid excessive acidity or alkalinity.

One of the tests that is helpful to differentiate fish-glue from animal-glue gumming is the so-called *spin test*, which is made by 'beating' an area of the gumming with a moistened finger, when it will be observed that the fish glue will spin out in long, fine threads. This is not an absolute test, however, as some animal glues, particularly those which have undergone hydrolyzing treatment, exhibit similar, but less pronounced, characteristics. Fish glues have a characteristic odor, and they are likely to be more hygroscopic than animal glues.

Fish glues are generally tested for viscosity, total solids, color, and salt content.

104. Dextrine.—In general, dextrines should be clean, light colored, relatively free from odor and taste, and readily soluble, to produce gumming solutions of the proper solid content and consistency for running.

Dextrine is tested for viscosity as received, and for the viscosity change of a standard solution after a certain period has elapsed. This is carried out by means of a standard glass viscometer, much after the same manner as described for animal glue.

Moisture, ash, soluble starch, reducing sugar, and acid reaction are other tests made. The relative amounts of reducing sugar and soluble starch may be taken as an indication of the hygroscopic and solubility characteristics.

Quickness of stick may be determined from gummed strips by a comparative test with a standard sample.

GUMMING FORMULAS AND APPLYING GUM

PREPARATION OF GUMMING FORMULAS

105. Mixing and Control.—The adhesive solutions are prepared in steam- or hot-water-jacketed kettles of the conventional paddle-stirring type. Copper- or glass-enamel-lined kettles are generally employed, to avoid corrosion by the adhesive solution. The usual precautions are observed to insure accurate weighing of ingredients and to avoid overheating.

Viscosities of all gumming solutions should be controlled within reasonable limits, to permit maintenance of a uniform condition at the gumming machine. In general, gummers plan to use as high a concentration of glue as will flow evenly on the machines.

106. Animal Glue.—The proper weight of ground glue is soaked in cold water for an hour or two, after which, solution is accomplished by gradually heating the mixture to a temperature of approximately 160°F. The solution is then cooled to a temperature of between 115° and 125°F. for application on the gumming machine. The working temperature varies with the kind and concentration of the glue, and is designed to maintain proper viscosity for flowing. Good practice decrees that one should avoid maintaining solutions of animal glues at temperatures exceeding 140°F., because of the degradation of the glue and loss of adhesive strength. Bone glue may be run at concentrations of 40 per cent or higher, depending on the viscosity of the glue.

107. Fish Glue.—Fish glue is liquid at ordinary room temperatures, and may usually be run directly on the gumming machines. It may be adjusted to the desired working viscosity by the addition of a small amount of water, or by raising the temperature.

108. Dextrine.—The desired weight of dry dextrine is added to cold water, with constant stirring. This mixture is heated gradu-

ally to a temperature of 180°F., and until a clear, light-amber-colored solution is obtained. Total solids may vary approximately from 40 to 60 per cent, depending upon the kind of dextrine and conditions of use. Dextrine solutions are usually sufficiently liquid when cool to be run at toom temperature on the gumming machines.

109. Blends.—Occasionally, there may be produced combinations of dextrine with animal or fish glue, or mixtures of fish and animal glue for certain uses.

Also, new water-remoistenable gummings of special composition have lately been developed to supply adhesion to a wide range of surfaces formerly considered difficult or impossible for water-activated types.

APPLYING THE GUM

110. Flow Sheet.—The diagram, Fig. 19, represents a convenient sequence of operations from the raw materials to the finished sheet, arranged in bundles for shipment. No detailed explanation is necessary.

111. Gumming Machines.—The diagrammatic sketch, Fig. 20, shows the plan of a comparatively simple gumming machine. On the unwinding stand is a roll of paper *A*; *E* is the pan containing the adhesive, which is distributed by the fountain roll *B* to roll *C*, which applies it to the paper. The pressure between rolls *D* and *C* is adjustable and regulates the thickness of coating.

So-called **surface gumming** may be employed by passing the paper directly over the top of roll *D* and around roll *T*, as indicated by the dotted lines. The tension of the paper against roll *D* supplies the pressure necessary to transfer the film of liquid glue from roll *D*.

Machines generally vary in width from 40 to 60 in., although for special purposes they may be even wider. Gumming machines of recent type contain a good degree of mechanical precision, and have the parts contacting the adhesive solution made of corrosion-resistant material.

112. Dryers.—The industry uses several distinct types of dryers; namely, the festoon, the squirrel-cage (or tension) type, and the cylinder machine. The tension types are probably more popular at the present time.

The *festoon type* allows the paper to hang in long loops during its passage through the drying chamber, which is maintained at

(Dry dextrine, glue
(water, etc. → Mixing kettle → Storage kettle → Liquid glue → Gumming machine

Paper rolls → Gumming machine

Gumming machine → Dryer → Breaker → Calender → Storage

Gummed tape → Slitter

Storage → Slitter → Packaging → Gummed paper in rolls

Storage → Sheet cutter → Inspection → Guillotine → Bundling → Gummed paper in sheets

FIG. 19.—Flow sheet for gummed paper.

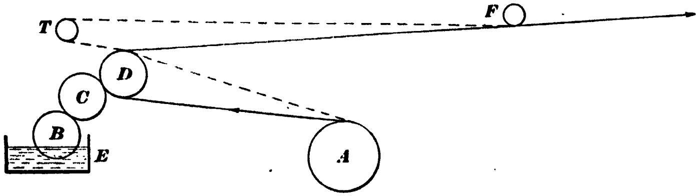


FIG. 20.

the proper relative humidity and temperature to prevent curling and, at the same time, to bring the moisture content down to the correct figure. This type is shown diagrammatically in

Fig. 21, in which the festoons are shown at G and the winder at W. Dryers of this type are used principally for label papers; they are supposed to have some advantages where the prevention

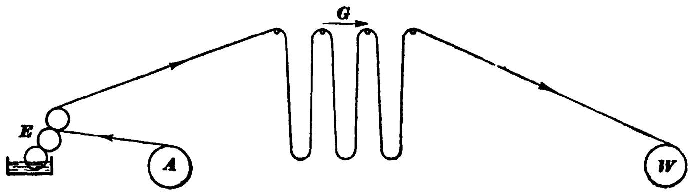


FIG. 21.

of curl is an important feature. The practical limit of speed is approximately 250 ft. per min.

The *squirrel-cage*, or *tension*, *type* of dryer is shown in Fig. 22. This type is characterized by the use of a much higher tempera-

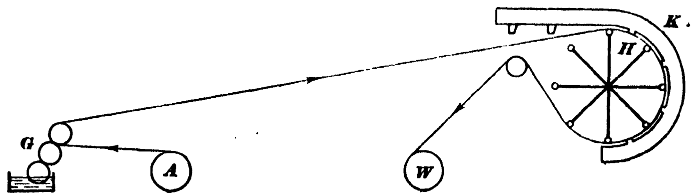


FIG. 22.

ture than the festoon dryer, and by the fact that the paper is held under tension during the whole process of drying, in order to prevent curling. The slatted wheel, or squirrel-cage, H, is

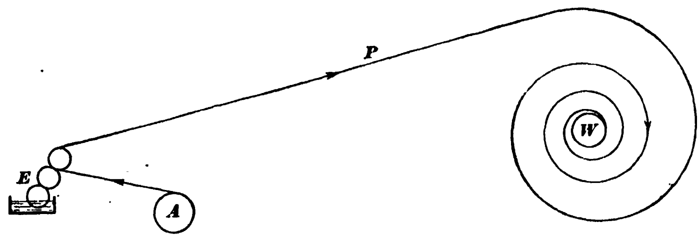


FIG. 23.

open, and hot air may be blown on both sides of the paper if desired. A hot-air duct is shown at K. The temperatures employed may be as high as 250°F., while drying speed is approximately 250 ft. per min.

The *Crowell dryer* is a machine of the tension type; it operates by taking the paper from the gumming machine and carrying it over a spiral frame, finally winding it up in the center of the spiral, somewhat after the manner indicated in Fig. 23. The drying speed is approximately 200 ft. per min.

The *cylinder type*, shown in Fig. 24, is similar to the squirrel-cage type in the fact that it holds the paper under tension during the process. Heat is applied, however, through the surface of the hollow cylinder L, which is filled with steam; drying speeds are rather low, from 15 to 40 ft. per min. This heat is usually supplemented by a blast of hot air, blown on the gummed side

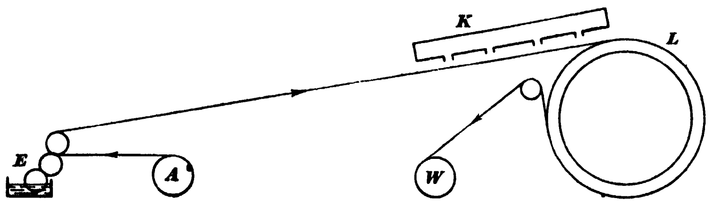


FIG. 24.

of the paper at K. This type is less desirable where non-curling qualities are important in the finished paper.

113. Breaking.—This is a very important step in the manufacture of gummed paper used for label or other purposes, where it is desirable for sheets to lie relatively flat. Normally gummed paper will curl *forward* (toward the gum) as it loses moisture or will *reverse* the curl (toward the paper side) as it picks up moisture from the surrounding air. This is due to the fact that the film of glue has a greater coefficient of contraction and expansion (with change in moisture content) than the usual paper body-stock. Breaking serves to crack the layer of glue into small sections, thereby producing a discontinuous film which is necessary for the elimination of severe curling tendencies. Gummed paper used for sealing tape and box-stay work is usually not broken.

A breaking machine is shown in Fig. 25. The roll of gummed paper A, with the gummed side out, is mounted on an arbor fitted with a brake B. The sheet passes over a roller C at a 45° angle, and thence over the edges of a square bar D; it then passes to a set of tension rollers, and is finally rewound on an

arbor at *E*. This operation breaks the paper in one direction only; hence, it is necessary to repeat the operation by passing

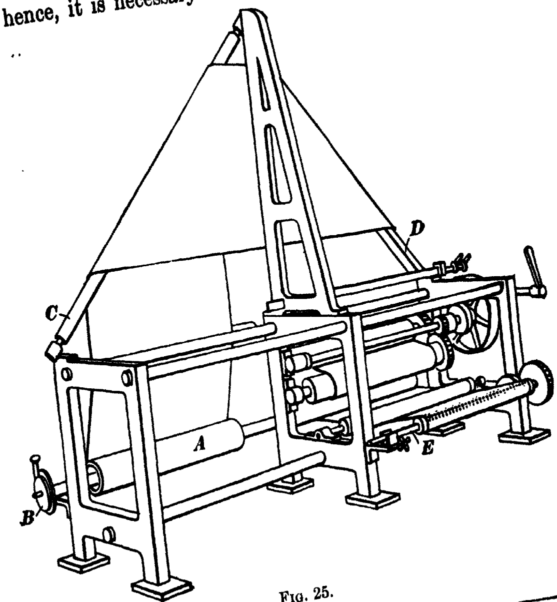


FIG. 25.

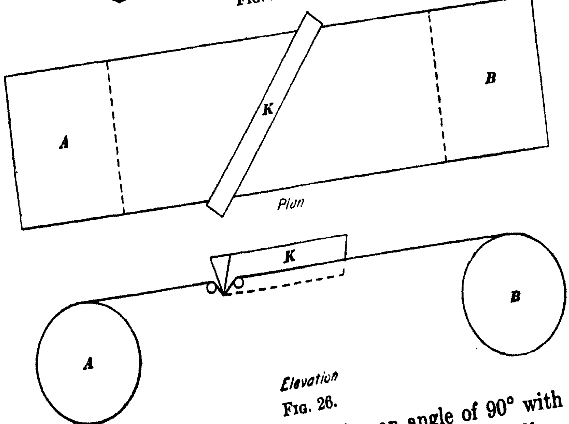


FIG. 26.

the paper under a second bar, making an angle of 90° with the first bar, in order to complete the breaking of the glue film.

A simple device for breaking the film is shown in Fig. 26. This consists of an unwinding stand for the roll of paper A, a winder B, and a knife K that rests on the plain side of the paper at an angle of 45° as the sheet passes over two supporting rollers. A second knife at an angle of 90° with the first may be used to complete the breaking of the film of adhesive.

Gummed papers are also broken by a combination of embossing roll with one or more breaking bars similar to those previously described. This method is characterized by simplicity of operation and low waste.

114. Finishing Operation.—The same type of finishing equipment that is used in the paper mill—described in the Section on *Paper Finishing*—is used in finishing the gummed paper; this includes stack calenders, sheet cutters, slitters, and guillotines.

115. McLaurin Gummed-Tape Tester.—This instrument is used to test the tack of gummed tape shortly after remoistening and before the taped joint has become dry. It consists essentially of a split metal table, so connected that upon release of a heavy pendulum, the two halves of the table are swung upward and apart. The gummed tape is moistened in any desired manner, either by roll or brush, and is laid on two sheets of paper (or other material) that have been clamped to the two halves of the table, thus forming a splice joining the two sheets. This tape splice is rolled immediately, once or twice across and back, with a heavy hand roller covered with rubber.

Upon completion of the rolling (or after a given time interval), the pendulum is tripped, causing the two table sections to swing up and apart, thus breaking the splice by pulling one or both ends of the tape from the paper. The force required to do this is measured by the amplitude of the pendulum swing—the less the amplitude the greater the force—and is indicated by a free pointer on a scale, in the same manner as that employed on the Elmendorf paper-tearing tester. A solenoid may also be used to trip the tester, the solenoid being actuated by a timer-relay that is started when the tape is moistened and cut.

Tape from 1 to 3 inches in width may be thus tested. The sheets to which the tape is applied measure 6 inches by 4 inches, and the tape itself is 6 inches in length. The results of the test are influenced by the width of the tape, method

of moistening, the time interval, temperature, humidity, and the nature of the sheets to which the tape is applied. The conditions of the testing should be largely dependent on the use requirements of the tape.

116. Packaging.—Sheets are usually packaged in standard sizes 17 × 22—500 and 20 × 25—500, in half-ream packages, suitably wrapped with waterproof paper to protect the gumming. Gummed paper is also shipped in roll form; and, for special uses in connection with sealing machines, the rolls are slit and rewound in narrow strips.

WAXED AND DECALCOMANIA PAPERS

WAXED PAPER

By E. A. Bradshaw

117. Origin.—The origin of waxed paper, dating back some fifty years, may be looked upon as one of the direct results of efforts to secure an undoubted supremacy of position for paper as a universal wrapping material. With the cheapening of the price of paper, due to the discovery of a process of its manufacture from wood pulp, the possibilities of its use as a wrapping grew to be limited only by its suitability; and one of the greatest of its shortcomings was the fact that, being porous, it was not moisture-proof. To make paper suited to the wrapping of goods in which it was desired either to retain moisture or to prevent the outside moisture from penetrating, it was necessary to find some cheap and practical way of closing the pores in the stock; and this has been accomplished by impregnating or coating the paper with paraffin wax.

MATERIALS USED

118. Paper.—The basic stock used in the manufacture of waxed paper is most commonly confined to sulphites, krafts, books, and manilas, all made especially by the various paper mills to meet the requirements of the industry, though some higher grade papers are occasionally used. The finish on waxed paper depends very largely on the finish of the dry stock. A particularly porous sheet will, for instance, absorb a great deal more wax than a

highly sized and finished stock; conversely, a moderately highly finished paper is desirable when impregnation is not such a requisite feature as is a surface load of wax.

119. Wax.—The paraffin wax used in the waxed-paper industry is a petroleum product; it is obtained only from the crude oil of a paraffin base and not from asphaltic-base crudes. Paraffin wax consists of a mixture of saturated hydrocarbons having similar formulas, ranging from about $C_{23}H_{48}$ to $C_{35}H_{72}$. The wax is produced by the refineries in three stages of manufacture, as follows: (1) *crude scale wax*, which is not used in the coating of papers; (2) *semi-refined wax*, which is used for the coating of papers employed in the wrapping of products that would not be contaminated by it (metal parts, etc.); (3) *fully refined wax*, which is the material most generally used in the waxed-paper industry.

The last variety being entirely free from oil, and being odorless and tasteless, is peculiarly suited to the coating of papers intended for the wrapping of foodstuffs. Because so great a part of today's waxed-paper output is for this latter purpose, a great many manufacturers will use no other class of wax. By specifying fully refined wax for all purposes, all risks of contamination of stock and tanks is eliminated. Refined paraffin wax is obtainable in varying degrees of hardness, from a melting point of 120° to 145°F. Different melting points are specified for waxed papers, according to the industry and the climate in which the stock is to be used.

METHODS OF COATING

120. Specifications.—Processing specifications may be roughly divided into two classes, according to the amount of wax used, and are expressed as a per cent of the wax on the basis weight of the paper. Thus, a paper of 20-pound basis weight (24 × 36 —500) required to be waxed to a finished weight of 30 pounds would call for a 50% wax load. In general, any waxing paper will absorb up to 25% of its own weight in wax without leaving any surface coating, and papers so impregnated are termed **dry waxed.** Such papers are used principally in the wrapping of products where the moistureproof feature is required to be retained to the greatest possible amount, but where surface coating would prove undesirable or injurious to the product.

Where a load greater than 25% of wax is used, a varying coating of wax will usually appear on the surface of the paper; and although such paper is also thoroughly impregnated with wax, the term **coating** is generally applied to this process. What is known as *sealing load* is generally obtained by loading the paper (stock) with from 50% to 75% of its own weight in wax, according to the class of dry paper being used. Stock so loaded can be used as a wrapping, and the outer edges are sealed down by placing alternately against hot and cold plates. Automatic wrapping machines, specially designed for this purpose, are used very largely by bakeries, confectioners, and other manufacturers of packaged goods.

121. Impregnation.—Although there are several different types of waxing machines, practically all of them employ the same

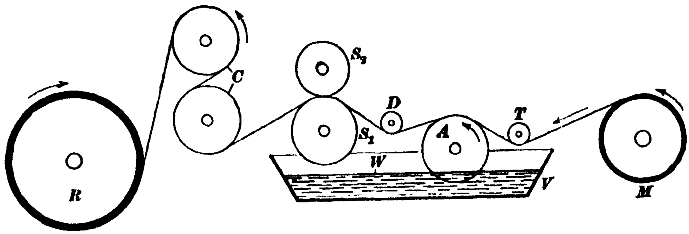


FIG. 27.

initial method of impregnation. One American-made machine is an exception to this, being almost purely a coating machine. On this machine, the paper on its way from the mill roll to the rewinder, see Fig. 27, passes two sets of rolls, which operate from separate wax tanks. These rolls coat the alternate sides of the paper with wax, which is then spread and regulated as to load by equalizer rods, thence passing over chilled rollers, and so on to the rewind roll.

Other machines are almost universally alike in that the paper is immersed in the wax tank. From this point on, the different machines vary as to the method of controlling the wax load. Most American machines depend on adjustable squeeze rolls, which operate along the lines of the ordinary domestic wringer. One German machine, used very largely in European countries, depends upon a set of adjustable scrapers.

On the American machine first mentioned, the paper may be coated on one side only by entirely cutting out one tank and set

of waxing rolls. The diagrammatic illustrations, Figs. 27 and 28, show the operation of a typical squeeze-roll type of machine.

122. Coating Lightweight Tissue.—Referring to Fig. 27, the paper is fed from mill roll *M*, under adjustable tension roll *T*, over advance roll *A*, under dip roll *D* (rolls *T* and *D* both out of contact with the wax), between the squeeze rolls S_1 and S_2, around the two cold-water rolls *C*, and thence to the rewinder *R*. The bottom squeeze roll S_1 is of chilled iron and is steam heated, while the upper roll S_2 is rubber covered. The advance roll *A* is the only roll here in contact with the wax, the level of which is indicated by *W*. The speed of the advance roll can be varied, thus varying the amount of wax that is applied to the paper; however, the speed of this roll is at all times very much slower than the speed of the paper, and the paper therefore coats itself by a wiping process. In order to obtain an even distribution of the wax, the area or length of contact of the paper with the surface of the advance roll can be increased or decreased by raising or lowering either the adjustable tension roll *T* or both rolls *T* and *D*.

The paper passes between the squeeze rolls without receiving any additional coating of wax, and they give it the desired finish.

It may here be pointed out that this process is typical of waxing one side only; also, that the heat applied to the paper by the bottom squeeze roll, when running tissues of very light weight, accomplishes the purpose of spreading the wax through the pores of the stock, thus thoroughly impregnating the sheet.

123. Coating Both Sides of the Paper.—To coat the paper on both sides, it is fed from mill roll *M*, Fig. 28, under adjustable tension roll *T*, over advance roll *A*, under dip roll *D* (which is entirely submerged in the wax), between the squeeze rolls S_1 and S_2, around the two cold-water rolls *C*, and to rewinder *R*. The advance roll *A* is in contact with the wax, but the amount of wax applied to the paper by this roll is entirely immaterial, the roll acting in this case as a guide roll only. The paper passes under the dip roll *D* and picks up wax on both sides as the roll guides it through the melted wax. The squeeze rolls press the paper and squeeze out the wax that is in excess of the amount of coating desired; they also give the paper the desired finish. The surplus wax drains back from the squeeze rolls into the tank.

124. Coating One Side of the Paper Only.—When it is desired to coat the paper on only one side, rolls T and D are raised, usually high enough to allow the paper from mill roll M to pass to tension roll T and *over* dip roll D without touching the advance roll A; it then passes through the squeeze rolls, around the cold-water rolls, and to the rewinder in the same manner as before. The level of the wax in the tank is raised to about the middle of the advance roll, which submerges, in part, the bottom of the squeeze roll S_1 in the melted wax. The wax is thus supplied to the bottom side of the paper by the bottom squeeze roll, and the paper itself keeps the wax from coming in contact with the upper

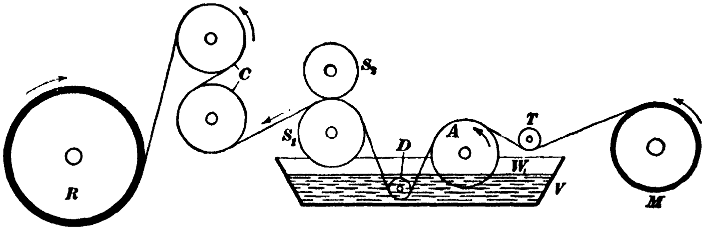


Fig. 28.

squeeze roll S_2. The amount of coating is regulated by the pressure between the two squeeze rolls, but mainly by the temperature of the melted wax and of the squeeze rolls.

125. Dry Waxing.—In this process, the machine is set as in Fig. 27, except that the upper squeeze roll S_2 is raised so as to be out of contact with the lower roll. The paper is fed from the mill roll M, under the adjustable tension roll T, *over* the advance roll A, under the dip roll, over the lower (heated) squeeze roll S_1, over the two cold-water rolls C, and thence to the rewinder R. The wax is applied by the advance roll, the only roll in contact with the melted wax. In this case, the squeeze rolls do not act as feed rolls, the feeding being done by the rewinder, the speed of which is controlled by a hand-adjusted friction device, which is governed by the operator. Long contact with the lower squeeze roll, which is heated, serves to spread the wax and force it into the pores of the paper.

A variation of this process, to secure heavier impregnation, consists in raising the level of the wax in the tank so as to submerge a part of the bottom of the lower squeeze roll, thus giving

the sheet a second coating, the amount of which is regulated by the speed at which the paper travels over the waxing rolls.

126. Recent Developments.—The greatest advance in coating paper with wax in the past few years has been in the direction of securing a higher finish. This has been accomplished to some degree by the sizing of the paper, but it is also attained by passing the waxed sheet through chilled water, which quickly sets the wax, giving it a gloss finish, not attainable by the chilled-roller method.

The water finishing method is briefly as follows: The paper is waxed on the usual squeeze-roll type of machine, but, instead of passing over chilled rollers, is immediately immersed in a tank of chilled water—the temperature of the water for best results being as close to the freezing point as possible without in any way congealing the water.

The paper travels around brass-colored rollers, then straight up in a vertical position for about 10 feet. From a point just above the water line, it is brought into contact with a suction arrangement which, while not affecting the finish of the paper, draws off the surface moisture. The paper travels around a roll at the top of the suction mechanism, then direct to the rewinder.

Another new development in waxed coating, which uses nitrocellulose lacquer, is now being developed. The outside of the sheet is coated with the lacquer to get a high gloss finish, the under side being coated with wax to effect a proper sealing under heat. This development is too recent to be fully discussed, but it has possibilities, especially in connection with carton wrapping where a very high gloss finish on the outside is desirable and where a waxed surface is necessary for sealing the package and for protection against moisture.

DECALCOMANIA PAPER

By C. A. Dickhaut

127. Explanatory.—The purpose of decalcomania paper is to transfer the accurate printing of the modern multicolored press to remote objects that could not otherwise be successfully put through the direct printing operation. This is accomplished by providing a medium between the printing ink itself and the body

stock that will, when moistened, break down and allow a separation between the two.

The use of such paper is very extensive and is exemplified in the modern home, where the thrifty householder, with the aid of decalcomanias and the various quick-drying colored lacquers now available, transforms antiquated furniture into objects of beauty. Decalcomanias are largely used, also, in the decoration of china, for transferring colored designs in inks that can be burned.

128. Details of the Process.—The process calls for a fairly hard-sized sulphite body stock (paper) containing as little stretch as possible. A starch coating is then applied to one side, dried, and the paper is rewound. The operation is again repeated, using a coating solution of part starch and part gum; the latter is applied to the starch-coated side, and it not only strengthens the ink print but it also provides the adhesion between the print and the object receiving the transfer.

Because of the necessity of uniform coating, free from ridges, etc., it is desirable to use a brush-type coating machine for both operations. Also, because of the curl experienced with starch coating, especially on a hard-sized stock, the arched pass dryer is preferable, since the paper is kept under tension and is slightly curved during the drying operation. In order to insure that the paper lie flat, a calendering operation is employed.

There are two kinds of decalcomanias—the slip transfer, and the direct transfer. When printing the latter type in multicolors, backgrounds are applied last; and before transferring this type of decalcomania, varnish or shellac is applied to the object, to provide the necessary adhesion. On moistening the backing paper, this peels off, leaving the colored ink in the desired pattern on the object.

PYROXYLIN, OR LACQUER-COATED, PAPERS

By Charles W. Stillwell

USES AND MATERIALS

129. Uses.—The manufacture of **lacquer-coated papers** is a fairly recent development, a natural outgrowth of the formulation of lacquers that will dry quickly on paper to form hard, glossy,

flexible, tack-free films. While the term **pyroxylin** refers to cellulose nitrate only, and is a familiar trade name, it is convenient to include hereunder those lacquers which contain other cellulose derivatives and resins.

Uses for lacquer-coated papers evolve from the decorative and protective value of these coatings. The glossy appearance of clear lacquer film is highly pleasing, and, when coated over printed matter, it serves to enhance the color value of the ink very effectively. A variety of decorative surfaces is in demand for labels and seals, box coverings and special wrappings, and may be produced by adding dyes, pigments, metallic powders, or combinations of these, to the lacquer.

At present, certain functional properties of lacquer coating, particularly greaseproofness, waterproofness, and moistureproofness (resistance to the passage of moisture vapor) are receiving close attention. These coatings are being developed to meet the requirements for the packaging of foods and other commodities where it is desirable to keep moisture in or out of a tight package. In a special sense, lacquer coatings may be applied to the papers to be used as gummings, activated either by heat or by non-aqueous solvents; reference has been made to these previously in connection with gummed papers.

130. Raw Materials.—Cellulose nitrate itself is a suitable film-forming material, as are certain other cellulose derivatives used in lacquer formulation. However, most film formers are too brittle to be used alone, and most commercial lacquers contain modifying plasticizers and resins. Pigments or dyes may be added when decorative lacquers are called for. The following are the principal raw materials employed by the manufacturer of lacquers and lacquered papers.

(1) Paper.

(2) Lacquer, which includes:

- (*a*) Film-forming material;
- (*b*) Modifying agents, such as plasticizers, resins, waxes, etc.;
- (*c*) Colors—pigments or dyes;
- (*d*) Solvents and diluents.

Certain properties of these materials must be carefully controlled to insure a satisfactory product.

131. Paper.—Coated or uncoated papers may be lacquered successfully. For economy and appearance, a paper that resists the penetration of lacquer is to be desired. Although highly absorbent papers and lightweight tissues are not ordinarily suitable for lacquering, crepe paper, which is made from absorbent tissue, can be lacquered successfully for certain decorative purposes.

The selection of a proper paper also influences to a large degree the smoothness and flexibility of the lacquer coating and the tendency of the sheet to curl under varying atmospheric conditions.

132. Lacquer: Film-Forming Material.—Cellulose nitrate, the oldest of the lacquer base materials, is still the most widely used, because of its relative cheapness, the toughness and hardness of its film, and the ease of its modification with a great variety of plasticizers and resins. It is usually made by treating a very pure cellulose (generally cotton linters) with a mixture of cellulose nitrate and sulphuric acid until the proportion of nitrogen in the product is between 11.2 and 12.4 per cent, corresponding to a mixture of the di- and trinitrates. Fully nitrated cellulose, trinitrate or guncotton, is not sufficiently soluble in the usual lacquer solvents. The conditions of nitration may be varied to produce nitrates of the same composition but of different viscosities.

The lacquer manufacturer is interested primarily in the average size of the cellulose nitrate particles, as measured by the viscosity of a standard dispersion. The viscosity of a particular sample is an index of its potential film strength and of the total solids obtainable at convenient coating viscosity. It is measured by a standard empirical method, which involves the time taken for a standard steel ball to fall through a column of a standard concentration of nitrocotton in a standard solvent mixture. Commercial nitrocellulose usually comes on the market in grades ranging from ¼ second and ½ second to 1000 seconds, and higher, though lower viscosity grades are sold for special purposes. The lower grades are selected when lacquers of high total solids are required, and when maximum strength and flexibility of the deposited film is not essential. With high-viscosity grades (70-second and higher), strong, flexible, non-penetrating films may be laid down, but the cost of solvents becomes a serious drawback, unless a solvent-recovery system is used. The grades

most widely used in commercial paper coatings are 4-second and 6-second, since they afford the best compromise between the several factors herein mentioned.

Cellulose acetate is frequently used in lacquers, and it is relatively fire resistant as compared with the nitrates. The use of the higher esters and of the ethers, such as methyl cellulose and benzyl cellulose, is being developed for the formation of lacquer coatings with specific properties. One of these film-forming materials is used in fairly large amounts in most commercial lacquers to impart the necessary strength and toughness to the film, although recently certain resins, such as the methacrylates, have been developed: these will probably find increasing use as film formers in lacquers.

Any grade of cellulose nitrate or other film-forming material should be clean and uniform in its dispersing characteristics, in order to be suitable for lacquer.

133. Modifying Materials: Plasticizers.—As the name implies, **plasticizers** impart softness and flexibility to lacquer films. True plasticizers are compatible with cellulose derivatives to which they are added. As compared with unplasticized film, the plasticized film is more flexible, the softening point is lowered, and the addition of large amounts of plasticizer causes the film to remain sticky at ordinary temperatures. True plasticizers are, in fact, solvents for the film former, with boiling points sufficiently high to prevent evaporation under normal conditions. Dibutyl-phthalate and tricresyl-phosphate are typical examples. Certain other materials, such as castor oil, are frequently used to soften nitrocellulose film, but they are not compatible with nitrocellulose: the system is a mixture rather than a true solution.

Plasticizers of an adequate and uniform degree of purity are commercially available.

134. Resins.—A wide range of resins, both natural and synthetic, is used in paper-coating lacquers. In a sense, soft resins are plasticizers. Certain resins are added to impart luster, and will often embrittle the film. Resin may modify the grease and moisture resistance of these films to specific solvents.

135. Waxes.—Lacquer films that are highly resistant to the passage of moisture vapors are made by the addition of 1 to

2 per cent of paraffin or other waxes. At present, this practice is covered by patents.

136. Colors.—Clear-colored films are made by using suitable dyes. They must be soluble in lacquer solvents, and it is usually desirable that they be fast to light.

Aluminum or bronze powders are added to lacquers to make the widely used, so-called silver and gold pyroxylin papers. The paper converter is interested in the covering power of the powders, which is, in turn, influenced by their size, shape, and dispersing properties. Powders commercially available vary widely in these properties, and careful selection is desirable.

To make opaque films having a glossy or matte finish, colored pigments are added to the lacquer. It is customary to grind the pigments into a lacquer base, to insure satisfactory dispersion. Particle size, light fastness, and dispersing properties are significant, and vary widely in available pigments.

137. Solvents.—The materials that will ultimately form the dried lacquer film are generally dispersed in suitable solvents, and they are spread on the paper in this form. These solvents are chosen to create the proper balance between true solvents and diluents; and the boiling-point range of the materials must be selected to control the rate of evaporation, which, in turn, influences the characteristics of the film. Alcohol, such esters as ethyl acetate and acetone, and certain higher boiling materials are the solvents: hydrocarbons, such as benzol and toluol, are typical diluents.

PREPARING AND APPLYING THE LACQUER

138. Hazards.—Since most lacquer solvents and diluents are highly inflammable, there is a serious fire hazard in the mixing and application of lacquers, which creates a special handling problem. All equipment should be well grounded to avoid static. Hammers and other tools that might strike sparks are to be avoided: where necessary, sparkproof alloys should be used. Motors should be vapor proof. Moving parts are frequently driven by belts from a motor in another room. Lights must be equipped with waterproof bulbs.

139. Mixing.—It is most convenient to disperse the nitrocellulose or other film-forming material in the solvent in an iron

kettle that is equipped with a paddle stirrer. If a resin is to be added, it is generally dissolved first, and then stirred in. Plasticizers and ground pigments may be added directly to the dispersed nitrocellulose.

140. Coating.—The dispersion, adjusted to a suitable viscosity, depending on the nature of the coating device and the desired characteristics of the coated sheet, is applied in one of several ways. Continuous roll coating is usually done with a doctor knife, or a reverse-roll coater. In the first case, an excess of lacquer is delivered to the paper behind a finely ground bronze or steel bar. As the paper passes under this bar, the thickness of the coating passing under it may be controlled by pressure on the bar. The roll-coating method is similar in general principles to a gumming machine. An adjusted amount of lacquer is applied to a roll, and is transferred from this roll to the paper. Standard equipment is available for coating paper in sheets.

141. Drying.—A typical nitrocellulose-lacquer coating requires about one minute to dry at a temperature of 240°F. The drying time increases as the available temperature decreases, and dryers must be designed accordingly. An essential feature of the (enclosed) drying equipment is an efficient exhaust system that will, at all times, provide sufficient air to maintain the solvent vapor concentration in the exhaust below the explosive range.

142. Hot-Melt Coating.—It has long been recognized that a protective film applied to paper as a molten mass and allowed to solidify quickly by cooling, should be cheaper than one laid down from a dispersion. However, until very recently, it has been impossible to formulate compositions that combine the necessary flowing properties when molten with the required degree of film flexibility and hardness. Satisfactory formulations are now well along in the experimental stage, and *hot-melt* coatings will probably become familiar as paper coatings in the near future. It is probable that these films will approach lacquer films in respect to gloss, greaseproofness, moistureproofness, and, to a lesser extent, flexibility. Their cost should be lower because: the amount of material required per unit area of paper is less, owing to minimized penetration of the coating material into the paper; running speeds are increased; there is no solvent loss; there is no fire hazard; and, finally, no expensive drying equipment is required.

COATED PAPERS

EXAMINATION QUESTIONS

1. (*a*) State some of the advantages of using coated papers. (*b*) Name five grades of coated paper, and mention their characteristics and uses.

2. (*a*) In general, what materials are used in preparing the coating mixture? (*b*) Discuss some of the properties of the clay used.

3. Discuss the use of paper as raw material, with special reference to its qualities.

4. (*a*) How is the clay slurry prepared? (*b*) How is clay tested for color and grit?

5. (*a*) What is satin white? (*b*) What are its particular advantages in connection with its use in a coating mixture?

6. (*a*) What types of dyes are used in coating papers? (*b*) What are color lakes, and why are they frequently used in preference to dyes?

7. (*a*) For what purpose is casein used? (*b*) Why must casein be used in solution, and how is the solution prepared? (*c*) Name its principal solvents.

8. (*a*) How is casein tested for adhesive strength? (*b*) for viscosity?

9. (*a*) Explain how glue is prepared for use in the coating mixture. (*b*) State the advantages and disadvantages of starch as an adhesive.

10. (*a*) When are waxes used in a coating mixture? (*b*) Name the waxes most generally used. (*c*) What materials are used for softeners and foam reducers?

11. Mention the equipment and functions of the coating-mixture room, and state the operations conducted in it.

12. (*a*) What are the general types of coating machines? (*b*) Describe one.

13. (*a*) What type of coating line dryer would you select, and why? (*b*) How is a double-coated paper dried?

14. (*a*) What is meant by machine coating? (*b*) by cast coating? (*c*) Describe the use of the air brush in connection with coating paper.

15. (*a*) What is the purpose of the friction calender? (*b*) Describe its operation. (*c*) Describe the operation of flint glazing.

16. What can you say regarding the stock in use for the production of friction, lithograph, book, and metal papers in connection with (*a*) basis weight? (*b*) finish? (*c*) sizing? (*d*) strength?

17. (*a*) For what purposes are gummed papers used? (*b*) State what qualities are desired in them.

18. What kinds of (*a*) adhesives and (*b*) papers are used in gummed papers?

19. (*a*) What types of dryers are used for gummed papers? (*b*) Describe one. (*c*) What is meant by *breaking?* (*d*) How is it done?

20. Describe, briefly, the process of waxing paper.

SECTION 5

PAPER TESTING

By B. W. SCRIBNER AND F. T. CARSON

PHYSICAL TESTS

INTRODUCTION

1. Why Paper Is Tested.—The reasons for testing paper are primarily: (*a*) to study its manufacture in order to improve its quality; (*b*) to maintain a previously determined quality; or (*c*) to ascertain whether the quality is equal to a previously determined standard, or conforms to a required specification. The manufacturer is chiefly concerned with (*a*) and (*b*), and the user or buyer is principally interested in (*c*).

This Section will deal briefly with the more common testing methods used in mill and laboratory: for further details, the standard testing methods of the Technical Association of the Pulp and Paper Industry should be consulted. The student should avail himself of every opportunity to learn more about the tests described, as well as numerous other less common or less important tests that cannot be taken up in this Section.

In the choice of tests to be made, it should be borne in mind that the purpose for which the paper is to be used is of primary importance, and tests should be chosen that will evaluate the qualities that are specifically desired. Because tests are required to epitomize in a very short space of time the necessary characteristics of paper, they cannot be perfect. The intelligent interpretation of the results of tests places a considerable responsibility on the observer, whose judgment can be replaced only to a slight extent by even the most detailed directions.

Relative to the testing instruments illustrated, other forms that are equally suitable are available, and they should be considered in securing testing equipment.

In the preparation of this Section on paper testing, liberal use has been made of the manual, "Paper Testing Methods," now out-of-print, which was prepared some years ago by the Committee on Paper Testing of the Technical Association of the Pulp and Paper Industry.

2. Sampling.—No test data can be more accurate than the sampling; consequently, great care should be exercised in sampling, and the samples should be drawn from a large number of different reams, bundles, or rolls. A single sample taken from a single roll or ream cannot truly represent the whole lot. The official method of the Technical Association of the Pulp and Paper Industry follows:

I. TEST SAMPLE: The test sample, unless otherwise specified, shall consist, where possible, of at least ten sheets not less than 11 by 11 inches in size. The sheets shall be kept smooth and flat, and be protected from exposure to direct sunlight, from contact with liquids, and from other harmful influences. Particular care should be exercised in handling the sheets if optical tests or tests for acidity are required, as such tests must be made on areas untouched by the hands.

II. PROCEDURE FOR SAMPLING: The sample sheets shall be so selected as to be as representative as possible of the entire lot of paper. Not less than 2 or more than 5 per cent of the total number of 'units' comprising a shipment of paper shall be sampled, nor less than 5 or more than 20 sets of sample sheets shall be taken in all. The units shall be cases, frames, or bundles, where a shipment consists of a large number of packages; or the units shall be fractions of the packages, where only a few constitute the shipment, such fractions or units comprising not less than 1000 sheets each.

Sets of sample sheets from sheet-cut paper shall each consist of 10 consecutive sheets; except for lots containing fewer than 10 units, when each set shall consist of 5 consecutive sheets; provided that, if there are reasons to believe that the paper was cut and stacked in single or any definite number of sheets together, each sample set shall also consist of that number. The sheets shall be taken from a point or points over ½ inch from the top or bottom of each frame, case, or bundle.

From rolls a single sheet shall be taken across the first unharmed layer; except when the shipment comprises less than 5 rolls, when the sheets may be taken across the first two unharmed layers.

The sample sheets shall be trimmed with their edges exactly parallel to the machine and cross directions of the paper.

The sample sheets comprising each set shall be consecutively numbered, and sufficient specimen sheets bearing consecutive numbers shall be taken for testing purposes, one from each set in rotation.

III. Procedure for Resampling: In case of necessity for resampling a lot of paper, the samples shall be taken as described above, except that they shall, if possible, be drawn from units different from those previously sampled.

3. Variability and Reproducibility.—Paper is not uniform in structure, and its properties vary somewhat from sheet to sheet, and also from place to place in the same sheet, as has been implied in the requirements for sampling. It is necessary to make a number of tests and to use the average as a measure of the property tested. Ten or more tests are usually made, although fewer are sometimes made when only a rough average is required, or when a few tests are a necessary compromise in a long, tedious test. A much larger number of tests may be required for a precise average. Tests are usually made in both the machine and the cross directions, or on both the wire and the felt sides, depending on the type of test. This custom, together with that of making a number of tests, will be understood to apply in the discussion of the various tests.

Because of the variability of paper, and also because of experimental errors inherent in the methods, it is not, in general, possible to reproduce a test value exactly. The degree of reproducibility will depend on the nature of the test, on the material tested, and on the conditions under which the test is made. It is necessary to make a reasonable allowance for these factors in the testing of paper.

4. Records.—It is very important that complete laboratory records be kept of all tests and of all original data. These records should be self-indexing, give full information, and be

adapted to ready reference. The best method of doing this is by means of printed cards, of a standard size, which can be filed

Serial No. ______ | FROM | Received ______
Folder No. ______ | | Reported ______

MARKED ______

Weight (25 x 40, 500) ______ lbs.
Weight (500) ______ lbs.
Thickness ______ inch
Bursting strength ______ pts.
Ratio B. S. to weight (25 x 40) ______ %
Folding endurance, double folds:
Machine direction ______
Across machine direction ______
Tensile strength, per 15 mm:
Machine direction ______ kg.
Across machine direction ______ kg.
Elongation:
Machine direction ______ %
Across machine direction ______ %
Tearing strength:
Machine direction ______ grams
Across machine direction ______ grams

Fiber composition: ______
Rag ______ %
Chemical wood ______ %
Ground wood ______ %
Coniferous ______ %
Deciduous ______ %
Manila and jute ______ %
Kraft ______ %
Ash ______ %
Resins ______ %
Opacity ______
Color ______
Gloss ______

REMARKS:

Department of Commerce
Bureau of Standards
Form 82a
Paper Test Record

Weight data: ______ × ______ × ______ = ______

Reported by ______
Checked by ______

(*a*)

	Bursting Strength	Thickness	Folding		Tensile		Elongation		Tearing		
			Mach.	Cross	Mach.	Cross	Mach.	Cross	Mach.	Cross	
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
Av.											
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
Av.											

(*b*)
FIG. 1.

in suitable boxes. The front and back of a record card used by the National Bureau of Standards, Washington, D. C., are shown in Fig. 1, reduced somewhat, the actual size being 5 by 8 inches.

This card gives all the information that is usually desired, and it may be readily altered to meet the specific requirements of the individual laboratory.

5. Divisions of the Subject.—Paper testing is customarily treated under three main heads: physical tests, microscopical tests, and chemical tests. A further division in the treatment of physical tests is convenient. Physical properties commonly tested will be considered in four groups: (*a*) *dimensional and extensive properties*, that is, properties related to the dimensions of the sheet or test specimen, or that depend on the amount of material considered; (*b*) *surface characteristics and optical properties*, since optical phenomena play an important part in the surface characteristics of a sheet; (*c*) *mechanical properties*, that is, strength and behavior under applied forces; and (*d*) *permeability to fluids*, that is, permeability to liquids, such as ink, water, and oil, and to gases, such as air and water vapor. The discussion of physical properties and testing properly begins with a consideration of the effects of humidity and temperature. After the various physical tests have been described, some specific effects of humidity changes on physical properties will be given.

DETAILS OF PHYSICAL TESTS

CONDITIONING, AND THE HYGROMETRIC STATE

6. Influence of Temperature and Humidity.—The direct effect of temperature alone on the behavior of paper is usually small for the range of temperatures at which paper is commonly used. The effect of humidity, which depends partly on the temperature, is, however, comparatively great. Paper is very sensitive to moisture changes. It expands and contracts, has a tendency to curl, becomes pliable or stiff, and changes in strength and other properties, depending upon the amount of moisture it contains. The reason that atmospheric humidity affects paper is that, together with temperature, it determines the moisture content of the paper. When paper is brought into an atmosphere of a certain humidity, there will, in general, be an interchange of moisture until the thirst of one or the other is satisfied. The relation between the moisture in the air and that in the paper is not a simple one. It is not a matter of water vapor simply flow-

ing from one to the other: there is always a change in the physical state of the moisture during the process; in the paper, the moisture becomes highly condensed. The moisture normally contained in a sheet of paper occupies much less than a thousandth part of the volume that the same amount of moisture occupies in the surrounding air. Although in a brief treatment, such as this, it is not possible to go into further detail about why paper takes up moisture and how this moisture is related to humidity, the above facts may help to explain why changes in the moisture content and in most physical properties of paper are correlated with *relative* humidity (ratio of the amount of moisture in the air to the amount in air saturated with moisture[1] at the same temperature, and usually expressed as a percentage) rather than with *absolute* humidity (actual amount of moisture in the air, usually expressed in grains per cubic foot or in grams per cubic meter). A familiar experience that further illustrates this relation between humidity and moisture content of substances is the feeling of dryness of the skin in heated air. This sensation is also correlated with relative humidity rather than with absolute humidity. Cold, moist air when heated up to a comfortable temperature in winter may feel very dry to the skin, even though the absolute humidity remains unchanged throughout.

It will be seen, therefore, that atmospheric humidity affects paper through its effect on the moisture content of the paper. As the fibers of paper absorb increasing amounts of moisture, they increase in diameter and become more pliable, losing in felting strength or bonding ability. Such alterations in the fibers affect the dimensions, the strength, the ease of wetting, and other physical properties of paper. The effects are considerable, and follow fairly rapidly the atmospheric changes. In order to obtain results that are at all consistent or reproducible, it is necessary to carry out most physical tests on paper in an atmosphere of definite *hygrometric state* (definite temperature and humidity). If the temperature variation is small, a constant moisture content and constant physical properties can be maintained in paper by keeping it in an atmosphere of constant relative humidity. The

[1] It is not quite correct to speak of air saturated with moisture, although it is a common expression, because water vapor in contact with paper exerts its characteristic effects whether there is any air present or not. Many laboratory experiments on moisture relations in paper and similar materials are carried out under vacuum.

standard hygrometric state for the paper industry is a relative humidity of 65 per cent at a temperature of 70°F. A well-insulated room specially equipped to maintain constant hygrometric conditions is the most satisfactory means of providing the required conditions. Air-conditioned cabinets, provided with means of manipulating the instruments and paper from the outside, have been used to a limited extent.

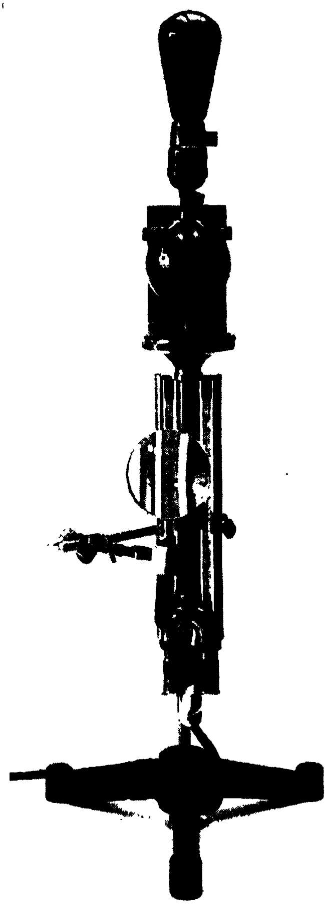


Fig. 2.

7. Measurement of Humidity. The humidity in a conditioning and testing room will be dependent upon the accuracy of the means provided for measuring it. In paper testing, as previously stated, we are not usually concerned with measuring the absolute humidity, but only the relative humidity. The most satisfactory device for measuring relative humidity is the **wet- and dry-bulb psychrometer,** of which the simplest form is the *sling psychrometer*. A psychrometer in which the thermometer bulbs are ventilated by means of a motor-driven fan incorporated in the instrument has some additional advantages. The principle is the same in either case. Two sensitive, accurately calibrated, matched mercury thermometers, Fig. 2, the bulb of one of which is completely covered with a clean tight-fitting envelope of thin fabric dampened with distilled water, are placed side by side and rapidly ventilated, either by slinging the psychrometer through the air or by passing a rapid stream of air over the bulbs. The cooling effect, produced by the evaporation of this water as the air under

observation passes rapidly over the bulbs, results in a depression of the wet-bulb temperature. The amount of the depression depends on the relative humidity, being small when the relative humidity is high and greater when the relative humidity is lower, since the water evaporates more rapidly the lower the relative humidity. The dry bulb shows the room temperature. The readings must be taken after the wet bulb has had time (usually a minute or two) to cool as much as it will under the conditions of the test, and before the fabric envelope has begun to dry out. By means of suitable tables or charts, the wet- and dry-bulb temperatures can be converted to the corresponding value for the relative humidity.

Another instrument frequently used to measure and record relative humidity is the **hair hygrometer.** It can be calibrated in terms of relative humidity because hair behaves much as paper and similar materials do, in that the expansion and contraction, as moisture is taken up from, or released to, the atmosphere, is correlated with the relative humidity. Very fine human hair is usually chosen for the actuating filament. A hair, being a single cell, responds to changes in humidity more reproducibly than most other substances that might be used for the purpose. Even the best hair hygrometer, however, is not a reliable standard of measurement. It is very useful to indicate or record changes in humidity, but must be calibrated frequently against a good wet- and dry-bulb psychrometer.

8. Conditioning Paper.—It is not sufficient to test paper in an atmosphere of constant humidity and temperature. Before being tested, the paper must be *conditioned*, that is, it must remain in this atmosphere for a sufficient time to become stable. Although paper responds quickly at first to a change in humidity, it continues to change slowly for a considerable time before becoming stable, and the best practice allows a seasoning or conditioning period of a day or more. A shorter period may suffice for thin papers, while a much longer seasoning period may be required for materials that respond slowly to changes in humidity.

In the following description of physical tests of paper, it will, in general, be understood that the paper must be conditioned and tested in an atmosphere of constant humidity and temperature if reproducible results are to be expected.

DIMENSIONAL PROPERTIES

9. Weight of Paper.—The weight of many familiar materials is conveniently expressed as its *specific weight*, that is, the weight of a unit volume, as, for instance, in pounds per cubic foot, pounds per gallon, or grams per cubic centimeter. The weight of paper, however, is usually expressed in such a manner as to indicate the weight for a given *surface area*, since the practical value of paper in most of its uses depends on the amount of *sheetage* rather than the volume of a given amount of material. The weight of paper, therefore, is commonly expressed in pounds per ream of a certain number of sheets of a certain size, or in grams per square meter. The ream usually contains either 480 or 500 sheets, although the 1000-sheet ream is used to some extent, and other sheet numbers occasionally.

Paper is made in various sizes to suit trade conditions. A given class of paper may be stocked in many different sizes, but it is not customary to designate the weight in terms of all these various sizes. Long-continued custom has established certain ream sizes as basic reference units to be used in reckoning or in specifying the weight of various kinds of paper.

If the weight of a certain paper, whether in a roll or in sheets of any size whatever, is given as 20 lb./(17 × 22—500), the meaning is that, if this paper were cut into sheets 17 inches wide and 22 inches long, 500 such sheets would weigh 20 pounds. The weight of a ream of this particular size and number of sheets, which is the basic[1] weight for writing papers, is known as the **substance number.** Other typical examples of basic weights used are the weights in pounds of the following ream sizes: 25 × 38—500, for book papers; 22½ × 28½—500, for bristols; 20 × 26—1000, for covers; 24 × 36—480, for wrapping paper. Uniformity in the use of basic weights does not prevail throughout the industry, however. Some would not regard all these as basic, either as to size of sheets or number of sheets, and many other basic reams would be included in a complete list. The confusion arising from such a lack of uniform practice has led to an effort to introduce the ream 25 × 40—500 as a single standard or basis on which to express the basic weight of all kinds of paper. This ream has a sheet area of 1000 square inches, and a total area

[1] Not to be confused with 'basis' weight commonly used; applies to a ream 24 × 36—500.

of 500,000 square inches, and is known as the **standard ream.** This standard ream, although having many obvious advantages, has not been widely accepted or used, since various paper mills are accustomed to using different basic weights. In each mill, the papermaking machines have long been calibrated in terms of a certain basic weight, the whole production schedule is geared to it, and the personnel best understand fluctuations, changes, and characteristics of their products in terms of this particular basic weight. The process of simplifying the expression of basic weight by means of a universal standard proceeds very slowly against the inertia of custom.

It should be clearly understood that the use of basic ream sizes and basic weights does not imply that papers so described in respect to weight are necessarily cut to these sizes for consumption, although this may have been the case in the early days of the manufacture of paper. The basic ream sizes are merely units or standards, dictated by custom, to which the weight of various kinds of paper is commonly referred.

10. Sheet Size and Ream Weight.—**Ream weight** is usually determined by weighing a single sheet on specially designed scales or balances[1] that indicate directly the weight of a full ream of sheets of the size of the one weighed. The size of this sheet must be accurately known. The paper, before it is weighed, may be cut to a known size with a template and sharp knife, or with a special cutter or trimming board. Otherwise, the length and width of the weighed sheet must be measured with an accurate rule or scale, such as a steel scale with a beveled edge, or thin edge, graduated in hundredths of an inch. These measurements should be made through the center of the sheet with the scale carefully lined up parallel with the edges. If the sheet weighed has been cut accurately to the size of the ream whose weight is desired, no calculations are required, and it is only necessary to read off the weight on the balance scale that corresponds to the number of sheets in the ream.

If the sheets are small, enough to aggregate approximately one sheet of the ream size desired should preferably be weighed at one time, and the length and width of each sheet must then be meas-

[1] A type of balance commonly used for mill-control testing is illustrated in *Papermaking Machines*, Section 1. More sensitive balances are preferred, however, for laboratory testing.

ured accurately in the manner described above. The total area of all the sheets weighed together is then computed and is regarded as the size of a single sheet of that ream whose weight is indicated on the scale of the balance. The computation of the desired ream weight from the data for this or any other size of sheet will be explained in the next article.

11. Computing Ream Weights: Conversion Factors.—To convert a given ream weight to any other ream weight is a simple matter. *The known weight divided by the total area of its ream gives the weight of one square inch of the paper. This quotient multiplied by the total area of the ream whose weight is sought gives the weight required.*

Suppose a sheet that measures 30.16 inches by 31.53 inches is weighed, and a reading of 57.3 is obtained on the 500-sheet scale of a ream-weight balance. Its weight may then be expressed as 57.3 lb./(30.16 × 31.53—500), that is, the paper weighs 57.3 pounds per ream, size 30.16 by 31.53 inches, containing 500 sheets. What is the weight of this paper on the basis of a ream of 480 sheets, 24 inches wide by 36 inches long? According to the rule given above, $\frac{57.3}{30.16 \times 31.53 \times 500}$ gives the weight of one square inch of the paper, since the area of one sheet multiplied by the number of sheets gives the total area of all the sheets in the ream. The total area of the basic ream, whose weight is desired, is 24 × 36 × 480. Therefore,

$$\frac{57.3 \times 24 \times 36 \times 480}{30.16 \times 31.53 \times 500} = 50, \text{ very nearly,}$$

and 50 lb. is the desired basic weight. Hence, the ream may be expressed as 50 lb./(24 × 36—480).

The rule given above can be written as a *conversion formula* in a form that is convenient for many purposes:

$$\text{Known ream weight} \times \frac{\text{area (sought)}}{\text{area (known)}} \times \frac{\text{number sheets (sought)}}{\text{number sheets (known)}}$$
$$= \text{ream weight sought,}$$

in which *area* (*sought*) means the area of one sheet of the ream whose weight is sought, and the other terms have corresponding meanings. It is obvious that factors can be worked out for the

CONVERSION FACTORS

Size of ream of known weight	Size of ream of weight wanted													
	16 × 21	17 × 22	17 × 28	18 × 23	19 × 24	19 × 28	20 × 26	20 × 30	22½ × 28½	24 × 36	25 × 38	25 × 40	36 × 36	sq. m.
16 × 21	1	1.113	1.417	1.232	1.357	1.583	1.548	1.786	1.908	2.571	2.827	2.976	3.857	4.613
17 × 22	.8984	1	1.273	1.107	1.219	1.422	1.390	1.604	1.715	2.310	2.540	2.674	3.465	4.144
17 × 28	.7059	.7857	1	.8697	.9580	1.118	1.092	1.260	1.347	1.815	1.896	2.101	2.723	3.256
18 × 23	.8116	.9034	1.150	1	1.101	1.285	1.256	1.449	1.549	2.087	2.294	2.415	3.130	3.744
19 × 24	.7368	.8202	1.044	.9079	1	1.167	1.140	1.316	1.406	1.895	2.083	2.193	2.842	3.399
19 × 28	.6316	.7030	.8947	.7782	.8571	1	.9774	1.128	1.205	1.624	1.786	1.880	2.436	2.914
20 × 26	.6462	.7192	.9154	.7962	.8769	1.023	1	1.154	1.233	1.662	1.827	1.923	2.492	2.981
20 × 30	.56	.6233	.7933	.69	.76	.8867	.8667	1	1.069	1.44	1.583	1.667	2.16	2.583
22½ × 28½	.5240	.5832	.7423	.6446	.7111	.8296	.8109	.9357	1	1.347	1.481	1.559	2.021	2.417
24 × 36	.3889	.4329	.5509	.4792	.5278	.6157	.6019	.6944	.7422	1	1.100	1.157	1.5	1.794
25 × 38	.3537	.3937	.5011	.4358	.48	.56	.5474	.6316	.675	.9095	1	1.053	1.364	1.632
25 × 40	.336	.374	.476	.414	.456	.532	.52	.6	.6413	.864	.95	1	1.296	1.550
36 × 36	.2593	.2886	.3673	.3194	.3519	.4105	.4012	.4630	.4948	.6667	.7330	.7716	1	1.196
sq. m.	.2168	.2413	.3071	.2671	.2942	.3432	.3355	.3871	.4137	.5574	.6129	.6452	.8361	1

two ratios in this formula, and that a conversion table of factors for the more common ream sizes would be a great convenience in converting from one to another of these common ream sizes. For example, if we wish to know the actual weight of a ream of 500 sheets, of the size 20 by 26 inches when the basic weight is known to be 60 lb./(24 × 36—480), we may apply the rule for conversion and indicate the computation as follows:

$$\frac{60 \times 20 \times 26 \times 500}{24 \times 36 \times 480} = 60 \times \frac{20 \times 26}{24 \times 36} \times \frac{500}{480}$$
$$= 60 \times 0.6019 \times 1.042 = 37.63$$

Ordinarily it will be necessary to put down only the last line of this computation, the proper factors being put in place of the two ratios in the formula above. Each factor is the ratio of the 'sought' to the 'known' quantity indicated. The first factor is obtained from a table. In the accompanying table of Conversion Factors, locate the column headed 20 × 26, the size of the ream whose weight is sought, and follow down to the row 24 × 36, the size of the ream whose weight is known, where the factor 0.6019 is found. The second factor will be 1.042 in going from 480 to 500 sheets, and 0.96 in going from 500 to 480, and is, of course, 1 when both reams contain the same number of sheets. If the ream weight obtained above is to be expressed to the nearest quarter pound, it may be recorded as 37¾ lb./(20 × 26—500).

12. Use and Calibration of Ream-Weight Balances.—Because the scale is graduated in pounds, one should not make the mistake of assuming he is weighing in multiples of a pound. The weights actually involved are very small fractions of a pound. Balances of this sensitivity are likely to be affected by air currents, and should be protected therefrom.

The balance is calibrated by placing accurate weights on the pan or holder in place of the paper. Since only one sheet of paper is weighed, and the scale shows the weight of 480, 500, or 1000 sheets, the scale automatically multiplies the actual weight by 480, 500, or 1000. Hence, the proper weight to use in calibrating a given mark on the scale must be the corresponding fraction of the indicated weight. For example, the 50-pound mark on the 500-scale corresponds to an actual weight of 0.1 pound, or 45.36 grams. If the pointer deviates from the mark when the proper

calibrating weight is on the pan, the amount of the deviation should be noted. A record should be made of the deviations all along the scale, and the corresponding corrections should be made in the indicated readings whenever the balance is used for weighing paper.

13. Ream Weight from Small Sample.—Sometimes it is necessary to find the ream weight of a very small sample of paper, in which case, the chemist's analytical balance must be used, and the length and width of the specimen must be very accurately measured. The same procedure is applicable also when the special ream-weight balance is not available, except that one should use a large sheet for the sake of the better sampling and greater accuracy.

The weight in this case will be in grams for a single sheet, and the calculation to ream weight differs from the usual computation only in converting this to pounds for, say, 500 sheets. Since 1 gram = 0.0022046 pound, the weight in pounds of 500 sheets of the size of the one weighed is 500 × 0.0022046 (or 1.102) times the weight in grams of the one sheet. The computation from then on is precisely the same as in the usual case.

As an example, suppose a small rectangular sample of book paper that measures 3.18 in. long by 2.29 in. wide is found to weigh 0.372 g. What is the basic weight of this paper? Since the basic ream for book paper is 25 × 38—500, and since 0.372 × 1.102 gives the weight in pounds of 500 sheets of the size of the sample, the computation is indicated in the usual manner, by means of the conversion formula, as follows:

$$0.372 \times 1.102 \times \frac{25 \times 38}{2.29 \times 3.18} \times \frac{500}{500} = 53.48, \text{ say } 53\tfrac{1}{2} \text{ lb.}$$

14. Weight of Paper in Metric Units.—In many foreign countries, the weight of paper is expressed in grams per square meter. Suppose one is told that the weight of a writing paper is 75.2 g./m.^{2}, and that he is to compute the substance number from this figure. The conversion formula is used in the same manner as for the above case, except that one must express the square meter in square inches (1 m.^{2} = 1550 in.^{2}), replacing 'area (known)' in the formula by 1550. The table of conversion factors includes the square meter. To find the substance number,

Art. 9, in this case, one recalls that the substance number means the weight in pounds of a ream 17 × 22—500, and substitutes in the conversion formula:

$$(75.2 \times 1.102) \times \frac{17 \times 22}{1550} \times \frac{500}{500} = 75.2 \times 1.102 \times 0.2413 = 20.00$$

The ream weight is therefore 20 lb./(17 × 22—500), and the substance number is 20. The origin of the part of the formula enclosed in parenthesis should be kept in mind, especially when reversing the calculation, *i.e.*, from a known ream weight to grams per square meter. For instance, to convert the substance number 20 to grams per square meter, reversing the above computation, we obtain:

$$\frac{20}{1.102} \times \frac{1550}{17 \times 22} \times \frac{500}{500} = 75.2 \text{ g./m.}^2$$

There are other short cuts and factors that are frequently useful in computations such as have been discussed in this and previous topics, but their introduction here would be more likely to confuse than to help the student.

15. Length of Paper in a Roll.—In the case of paper used in a continuous roll, such as newsprint, wallpaper, bag and wrapping paper, it is frequently necessary to calculate the length of paper in a roll. If the ream weight of the paper, the weight of the roll of paper, and the width of the paper in the roll are known, this calculation is easily made. The weight of the roll divided by the ream weight gives the number of reams that could be cut from the roll, and this number multiplied by the total area of all the sheets in one ream gives the total area of the paper in the roll. This area divided by the width of the paper in the roll gives the length of the paper in the roll, which will be in inches, since the other units used are inches and pounds. Hence, to get the length in feet, divide the length in inches by 12. The computation may be indicated by the formula:

$$L = \frac{Wbcn}{12wB}$$

in which, L = length, in feet, of paper in roll;
W = weight of the roll, in pounds;
w = ream weight, in pounds;

b = width of sheet in the ream, in inches;
c = length of sheet in the ream, in inches;
n = number of sheets in the ream;
B = width of paper in the roll, in inches.

As an example, a roll of newsprint, 32 lb./(24 × 36—500), having a width of 72 in., weighs 1500 lb. without the core. What is the length of the paper in the roll? Substituting the given data in the above formula,

$$L = \frac{1500 \times 24 \times 36 \times 500}{12 \times 32 \times 72} = 23{,}438 \text{ ft.}$$

16. Thickness and Bulk of Paper.—The **thickness** of paper is measured with some form of micrometer, in which a single sheet is held under a *given pressure* between two circular, plane, parallel surfaces, called the *anvil* and the *plunger* or *pressure foot*, while the precise mechanism of the micrometer indicates the distance between the two surfaces. The dial micrometer, Fig. 3, graduated in thousandths of an inch, or sometimes in ten-thousandths of an inch, is the type commonly used, although the machinists' micrometer is sometimes used. The pressure must be applied gradually, without impact. In the board trade, one thousandth of an inch is commonly called a **point,** and a board 0.050 inch thick, for example, would be termed a 50-point board.

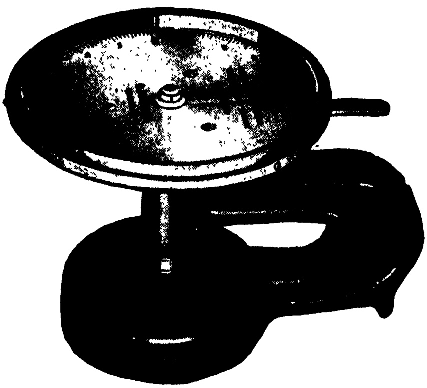


FIG. 3.

The average thickness obtained by measuring a pile of sheets at once and dividing by the number of sheets in the pile is called the **bulking thickness**; it is usually not the same as the thickness measured on a single sheet, because of a packing or nesting effect of the surface irregularities. Bulking thickness is important when many sheets are to be used together, as in a book. The term **bulk** is frequently used to mean the thickness of a certain

number of pages or sheets, although this term is used in other senses also.

A thickness gauge or micrometer is a rather delicate mechanism, and should be calibrated periodically by comparing the readings with the accurately known thickness of standard metal plates or gauge blocks.

17. Volume Relations; Air Space.—The specific volume of paper is the volume occupied by a unit weight of the paper. It is usually expressed in cubic centimeters per gram, (cc./g.) and is the opposite or reciprocal of *density*. A bulky paper is one having a high specific volume (low density) and a large percentage of air space. The specific volume is obtained by dividing the apparent volume (product of length, width, and thickness) of a sheet of paper by its weight.

The approximate volume occupied by the solid constituents of a sample of paper can be calculated from the chemical analysis and the density of each constituent (fiber, ash, resins, etc.). The volume of each constituent is the weight of that constituent in the sample divided by its density. The sum of the volumes of all the solid constituents in a sample subtracted from the apparent volume of the sample gives the **air space,** which is usually expressed as a per cent of the apparent volume. The air space is usually from one-third to one-half of the apparent volume of a sheet of paper, but may be more for a very bulky sheet.

18. Expansion and Contraction.—Small changes in the dimensions of a sheet are sometimes very significant, as, for instance, expansion or contraction of a sheet between impressions in multicolor printing, or change in the dimensions of recording charts. Excessive expansion of wallboards may cause serious buckling. Expansion or contraction is determined by taking the difference between measurements on the same dimension at two or more hygrometric states. The measurements can be made with a steel scale, in much the same way that ream size is measured, except that the measurements must be more precise. A large sheet is measured with a correspondingly long scale of special construction when considerable accuracy is required. The scale is graduated near one end only. Fine lines, or *fiducial marks,* are located at convenient intervals along the scale, which is so placed that one of these marks is over one edge of the sheet when the

opposite edge is under the graduated portion of the scale. Magnifying lenses are used to set the fiducial mark accurately and to read the length on the graduated end, or to set the slider if the scale is equipped with vernier or micrometer head. The readings are made to thousandths of an inch.

Instruments have been made also in which the expansion or contraction of a strip of paper moves a pointer over a graduated scale that shows the amount of the expansion or contraction.

SURFACE CHARACTERISTICS AND OPTICAL PROPERTIES

19. Wire Side and Felt Side.—To distinguish between the wire side and the felt side, fold over one corner of the paper, bringing both sides into view at the same time. The rougher surface of the wire side is often distinctly seen, with its regular pattern of diamond-shaped impressions left by the wire, although in some papers the wire marks do not stand out at all plainly. Frequently, they can be made more prominent by plunging the sample for a moment into water, or a weak caustic solution, and then draining or blotting off the excess moisture. The fibrous structure is thus made to expand, undoing the work of the calenders, and partially restoring the texture of the sheet as it was on leaving the machine wire. This dampening will often permit the wire marks to be seen plainly, even though they may have been indistinguishable before dampening. This method is often satisfactory for coated papers. Sometimes there is a slight difference in the brightness of the two surfaces that can be correlated with experience to distinguish between wire and felt sides.

20. Finish.—**Finish** is a term loosely descriptive of the contour, texture, and characteristics of the surface of paper. Among other things it embraces smoothness, appearance, softness, fuzziness, absorptiveness, and printing quality. Of these, smoothness is the property most frequently evaluated as an expression of finish.

Smoothness is evaluated in at least three different ways: by the friction against another surface; by the rate of flow of air between the paper and another surface in contact with it; and by the measurement of gloss.

Smoothness as measured by friction is usually evaluated in terms of the angle through which an inclined plane is tilted in

order for a specimen of paper, under a definite pressure, in contact with the inclined plane to begin sliding down. The surface of the inclined plane may be a standard surface or another piece of the same paper.

Smoothness as measured by air flow is usually evaluated in terms of the time required for a given volume of air under a given driving pressure to flow out between a specimen of the paper of given size and shape and a standard surface held in contact with the specimen under a definite pressure. Smoothness evaluated in this manner is often called *printing smoothness*, since a degree of correlation has been found between this test and practical printing quality.

Smoothness as evaluated by gloss will be discussed in the next article.

21. Gloss.—Although finish, smoothness, and gloss are sometimes used synonymously, it is usually recognized that **gloss** is only one of a number of elements in the finish of paper. The measurement of gloss is somewhat arbitrary, and the relative values obtained for a set of papers will depend on the kind of instrument used, and on the manner of illuminating and viewing the specimen.

One of the most commonly used instruments, known as a **glarimeter,** measures a form of contrast gloss. The instrument makes use of the fact that, when light is thrown on paper at a certain angle, that part of it which is reflected in a mirror-like manner from many small glossy areas substantially parallel with the plane of the paper, producing the sensation of glossiness, is almost completely polarized. A suitable photometer placed in the path of the light reflected at the same critical angle is able to measure the fractional part that has been polarized. The instrument is shown diagrammatically in Fig. 4, in which light from a source B is reflected from the paper P through the *photometer* (an instrument for comparing the intensity of one source of light with that of another) and into the eye at E, which sees an illuminated field divided into two parts. The two halves of the field are made equally bright by rotating the Nicol prism N Art. **79**) with a lever that moves a pointer along a scale. The scale reading, when suitably transformed, gives a measure of the glossy reflection as a per cent of the total light reflected into

the photometer. In another instrument, the relative gloss is measured as the relative brightness of two light beams reflected at two different angles, and brought together for comparison through an appropriate optical system.

Still another type of instrument, which is adapted particularly to glossy surfaces, measures the mirror-like reflection at any desired angle in comparison with that from a standard glossy surface illuminated and viewed in the same manner. There are other types of gloss and other instruments that are of less importance in paper testing.

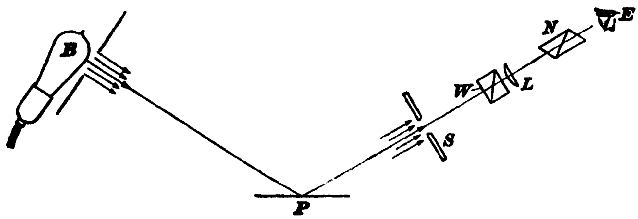


FIG. 4.

22. Formation.—**Formation** is judged by the degree of uniformity in the transmission of light when a sheet is looked at against the light. The sheet is said to be *well closed* when the fibers are so evenly distributed that the light is uniformly transmitted all over the sheet, or when the light and dark areas are very fine grained. Formation is said to be *wild* when the fibers are so unevenly distributed that they appear in clots, or dark patches interspersed with lighter streaks and patches, that is, when the light and dark areas are coarse grained. Although formation is ordinarily judged only in a qualitative manner, instruments have been designed for the purpose of measuring this property numerically.

23. Opacity.—**Opacity** in paper is chiefly important in preventing ink on the opposite side, or on the page underneath, from showing through. A comparison of two papers can be made by placing them edge to edge over a black line, and judging which is the more opaque. Another qualitative test uses a sheet of printed letters of various sizes underneath the sheet to be tested. The relative opacity is rated by the smallest letter that can be recognized through the paper.

The definition and measurement of opacity are somewhat arbitrary. The definition most widely accepted is that which expresses opacity as a *contrast ratio,* which is intended as a measure of the lack of contrast noted when paper is viewed against a black background and a white background. Opacity as thus defined is the ratio of the brightness of the illuminated paper when backed by a standard black background to its brightness when backed by a standard white surface and identically illuminated. In one instrument, the brightness ratio is measured with a photometer containing a divided field that receives reflected light from the two areas backed by the standards. The two halves of the illuminated field are matched by rotating a Nicol prism, the angular displacement being indicated on a scale. This ratio is sometimes expressed as a per cent by multiplying by 100; paper which is perfectly opaque has 100 per cent opacity. In another instrument, the contrast ratio is measured by the ratio of two readings of a meter that registers an electrical current proportional to the illumination received by a photoelectric cell from each of the areas backed by the standards. In this instrument, there is also provision for replacing the standard white surface by a pack of the paper being tested, in which case, a measure of opacity is obtained that is defined as the ratio of the brightness of the paper backed by a standard black background to its brightness when backed by a large number of sheets of paper identical with itself, simulating the condition obtaining in a book. This quantity is usually called *printing opacity.*

Opacity is also defined as the reciprocal of the relative light transmission of paper. In one instrument, the transmission is relative to that of a standard sample, being determined in a photometer consisting of two identical electric lights shining through the standard and the unknown placed side by side. The position of the light shining through the unknown is varied until the two specimens appear the same. *The square of the ratio of the distance between the standard and its light source to the distance between the unknown and its light source* is a measure of the opacity as defined by this instrument. In other instruments, the transmission is relative to that through air. A micro-ammeter, and a photoelectric cell at a fixed distance from a light source, measure the transmission through the paper placed in the light path relative to the transmission after the specimen has been removed.

The relative transmission is sometimes reported as *transparency*, without commitment as to the definition of opacity. Another instrument, less commonly used, measures the relative transmission by the number of sheets required to obscure the outline of a window or opening in a box illuminated by a standard light source. By this method, also, opacity is defined as the reciprocal of the relative transmission of light.

24. Color.—The measurement and specification of the **color** of paper are rather difficult. The whole subject of color measurement is quite technical, and the student who wishes to make a special study of it will find a considerable literature on color.

Many instruments are available for measuring color, and the measurements are made in different ways. Some instruments measure, by means of a photometer, visual or photoelectric, the relative brightness of light of different colors reflected from the surface of paper. With some instruments, three colors, red, green, and blue, are used to represent the color characteristics over the spectrum. With others, the relative brightness for a number of colors is determined. A curve is usually plotted to show the relative brightness for the different parts of the spectrum. A pure white will reflect all colors equally; whereas a colored paper will reflect unequally, the relative brightness at different parts of the spectrum giving a description of the color characteristics of the paper.

Another important class of *colorimeters* obtains a measure of the color of paper by matching it with a mixture of light of different colors, red, green, and blue, or a mixture of white light with light of the dominant color.

The student will soon discover, if he has not already done so, that the color of paper is not a simple property, and that the color observed will depend somewhat on such circumstances as the surface texture of the paper, the degree of opacity, and the kind of light in which the paper is viewed.

25. Dirt and Foreign Particles.—Dirt and contrasting specks in paper that detract from the appearance can be roughly evaluated by counting the number in a given area of paper. Large particles are more objectionable than small ones, however, and the relative area covered by such foreign particles can be estimated by comparing each speck in a given area with black spots

of various sizes and shapes on a standard chart, picking out in each case the black spot that gives the same visual effect as the speck under observation, and taking the sum of all such areas as indicated on the chart.

The identity of a bit of dirt or foreign particle can usually be determined by chemical means, with the aid of the microscope. This is discussed later under microscopical tests.

Thin papers used in condensers or for other electrical purposes can be rapidly explored for conducting particles that extend through the sheet by laying the sheet on a smooth metal plate, and running over it a small feeler electrode connected to the plate through a battery and current detector (voltmeter, galvanometer, or telephone head set).

26. Abrasion; 'Wet-Rub' Test.—A mechanical wet thumb that rubs up the surface of paper, giving a numerical evaluation of a time-honored test, has been described by the National Bureau of Standards. Such a test is important in the case of most surface-treated papers, such as blueprint, map, and ledger, and papers that are handled and used while wet.

MECHANICAL PROPERTIES

27. Influence of Grain; Determining Machine Direction.—Paper, like wood, has a *grain*, which results from a predominance in the orientation of fibers along the direction of travel on the papermaking machine, that is, in the *machine direction*. Tests of strength and other mechanical properties must be made and recorded with reference to the two cardinal directions of paper, since paper is generally stronger in the machine direction than in the crosswise direction, or *cross direction*, as it is usually designated, and other properties may differ in the two directions. The machine direction (also called *grain direction*, or with the grain) can be determined in several ways.

The machine wire usually imparts to the paper a wire mark, which consists of a pattern of diamond-shaped marks having their longer diagonal in the machine direction. In a favorable light, the wire mark may indicate the machine direction at once.

If a small square of paper is wetted on one face with water, it tends to curl up into a cylinder with the axis in the machine direction and the curvature in the cross direction. Sized paper may

be floated, but unsized paper must be touched only momentarily to the water surface if the curl is to be observed.

A common test for direction depends on the fact that paper is *stiffer* in the machine direction than in the cross direction. A slender strip (say $\frac{1}{2}$ in. by 6 in.) is cut parallel with one edge of the sheet, and another of the same size is cut at right angles to the first. The two strips, one on top of the other, are held by one end in a horizontal position and then rotated half a turn to reverse their relative positions. When the cross-direction strip is underneath, it will bend the more and fall away from the stiffer machine-direction strip; but, when the cross-direction strip is on top, the two strips will remain in contact.

Another common method depends on the fact that the stretch of paper at rupture is less in the machine direction than in the cross direction. Because of this fact the machine-direction structure always gives way first in the bursting test, making the initial line of rupture (which is the longest line parallel with an edge of the sheet and usually through or near the center of the burst area) run at right angles to the machine direction.

In general, the direction tested, in the evaluation of strength and other mechanical properties, is *the direction at right angles to the chief line of rupture*, or to the axis of creasing or bending, Art. **32**, because this rupture line or bending axis must run crosswise of the fibers that suffer chiefly in the test. Custom, however, makes an exception in the case of the tearing test.

28. Tensile Strength; Stretch.—The tensile strength of paper is determined from the load required to pull apart a strip of paper of known dimensions. There are several types of tensile testers, but the one most commonly used for testing paper is the *pendulum type*. The two ends of the strip to be tested are held in clamps, the lower one of which is moved steadily downward by means of a screw or hydraulic mechanism driven by hand wheel or motor. As tension is thus applied to the specimen, and thence to the upper clamp which actuates a pendulum, Fig. 5, the pendulum swings outward, and, by the increasing leverage, balances or weighs the tension on the specimen, much as a quadrant scale weighs a sheet of paper. When the strip of paper breaks, pawls take hold and keep the pendulum at the highest position reached, permitting the breaking load to be read from a scale, graduated

usually in pounds or kilograms. A standard length of strip between clamps is necessary, because a short strip ordinarily gives a higher reading than a long strip does. The breaking load is proportional to the width of the strip, and the strength of the

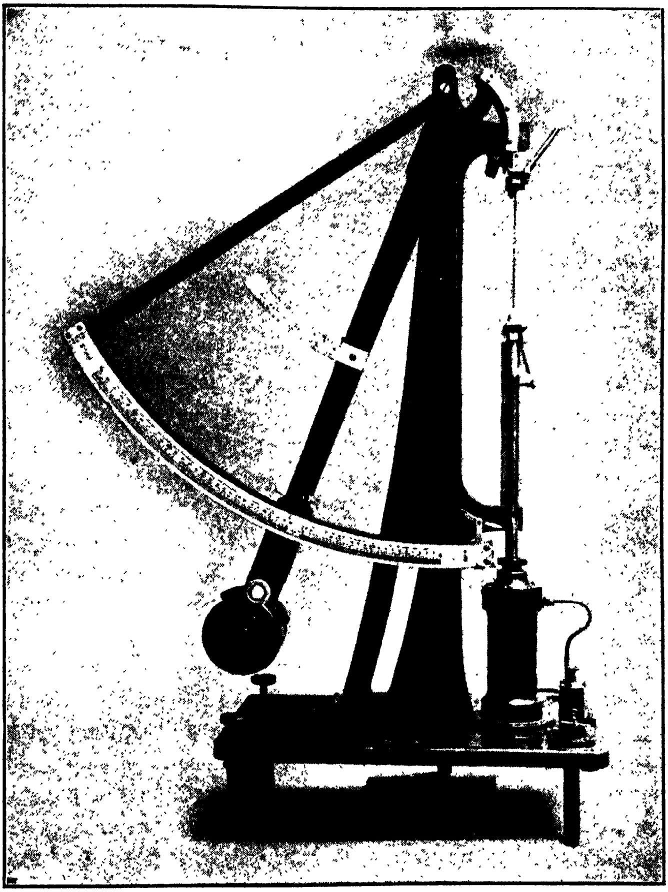


FIG. 5.

paper is commonly expressed as pounds per inch width, as kilograms for a width of 15 millimeters, or as kilograms per centimeter width. The breaking load for a unit width thus expressed is frequently designated as **tensile strength,** although the tensile strength of most materials is the breaking load for a unit cross section, expressed, for example, in pounds per square inch. The

term **breaking strength** is often used to designate the breaking load per unit width.

The width of strip perhaps most commonly tested is 15 millimeters. The following conversion factors are given for the conversion of breaking strength from one unit to another:

1 kg./15 mm. = 3.733 lb./in. = 0.6667 kg./cm.[1]

The tensile testing instrument is calibrated by hanging known weights to the upper clamp and noting the readings on the scale, much as a ream-weight balance is calibrated.

Stretch, as commonly understood in paper testing, means the elongation at rupture under tension, and is usually expressed as a per cent of the original length. Most tensile testers have auxiliary equipment for measuring the stretch at the same time the breaking load is determined.

29. Breaking Length.—The **breaking length** of paper is the length of a uniform strip just sufficient to cause the strip to break under its own weight when suspended by one end, that is, it is the length of a strip of any width whose weight equals the breaking load for that width. The significance of breaking length lies in the fact that it is roughly proportional to the conventional tensile strength referred to a unit cross section (pounds per square inch, for example). It is therefore a measure of the intrinsic strength of paper as a material rather than as a sheet. Since the breaking length of most paper is several miles, and could be directly measured only with the aid of a stratosphere balloon, it is always calculated from the breaking load determined with the tensile tester, together with other known data.

Dividing the tensile breaking strength (expressed as pounds per inch width) by the weight of the paper per square inch (quotient of ream weight by the total area in the ream) gives the breaking length in *inches*. Breaking length could as well be called the *strength-weight ratio*. It is evident from this operation why the breaking length is roughly proportional to the conventional tensile strength, because the weight per ream is approximately proportional to the thickness, at least for a given kind of paper; and, hence, the operation amounts, in effect, to dividing the breaking

[1] In practice, these constants are taken as 3.73 and 0.667, respectively. They are here given to four significant figures to conform with the other conversion factors.

strength, in pounds per inch width, by the thickness. That is, the breaking length is approximately proportional to the strength in pounds per square inch of cross section. Breaking length is customarily expressed in meters or yards.

To express the foregoing as a formula, let

L_y = breaking-length, in yards;
t = average breaking load, in kg., on strip 15 mm. wide;
b = breadth of sheet in ream, in inches;
c = length of sheet in ream, in inches;
n = number of sheets in ream;
W = weight of ream in pounds;

then,

$$L_y = \frac{t \times 3.733 \times bcn}{W \times 36}$$

or

$$L_y = \frac{0.1037tbcn}{W}$$

As an illustrative example, suppose 10 representative strips, each 15 mm. wide, cut in the machine direction from a sample of book paper 65/(25 × 38—500), have been tested, and the average breaking weight was found to be 5.33 kg. Then, the corresponding machine-direction breaking length is, substituting in the formula,

$$L_y = \frac{0.1037 \times 5.33 \times 25 \times 38 \times 500}{65} = 4039 \text{ yd.}$$

If the breaking length is desired in meters, multiply the result just obtained by $\frac{36}{39.37} = 0.9144$, obtaining $4039 \times 0.9144 = 3693$ m.

30. Wet Tensile Strength.—Some papers, such as photographic papers and blueprint and brownprint papers, are sometimes tested for strength while wet. The test is made in a manner similar to that for the ordinary tensile strength, except that even greater care is required in clamping the strip without distortion, and in carrying out the test in a reproducible manner. Because of the weakness of wet paper the tensile tester should be as sensitive as possible. The scale can be spread out somewhat by operating the tester with the pendulum weight removed and the apparatus

recalibrated for this condition. Standard time of immersion and temperature of the water (usually 20 minutes at 70°F.) must be adhered to.

31. Bursting Strength.—The **bursting,** or 'pop,' **test** (often referred to as the Mullen test) is one of the most familiar tests made of paper and fiber boards. A common type of instrument is shown in Fig. 6. The sheet is clamped firmly beneath a metal ring, through which the paper is forced to bulge by means of hydraulic pressure applied underneath. The pressure induced is indicated by a maximum-reading pressure gauge, which registers in pounds per square inch the pressure attained when the paper has been forced to bulge so much that it bursts. The fluid medium in the Mullen type of tester is confined by a rubber diaphragm. In another design, air pressure is used to burst the specimen. Some instruments are motor-driven, and have automatic features designed to eliminate errors ordinarily attributed to hand operation.

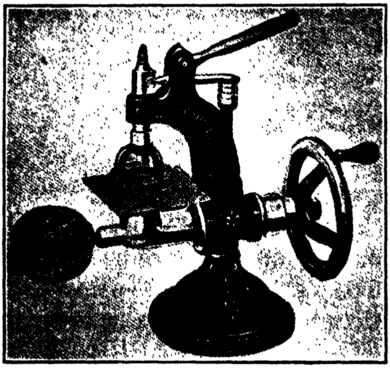


Fig. 6.

The popularity of this test depends not only on the ease with which the test is made but also on the combination of strength, 'give,' and toughness in a way that serves as a practical measure of the serviceability of paper in various applications. It is widely used in mill control and in specification testing. It has the disadvantage, however, that it does not give an indication of the cross-direction strength. The bursting test depends in a complicated way on the machine-direction tensile strength and stretch, and on the size of the burst area. In common with the tensile test, it depends on the rate of applying the pressure or load. The bursting pressure for a standardized, circular area is the measure commonly taken for the bursting strength, and is sometimes recorded as *points*.

In other types, designed more particularly for testing fiber boards, the specimen is burst by forcing a metal plunger or ball through it.

Bursting strength is frequently expressed as a strength-weight ratio, called **points per pound**,[1] which serves a purpose similar to that of the breaking length. By means of this ratio, it is possible to compare the intrinsic strength of papers of different weights.

The calibration of the bursting tester consists chiefly in the calibration of the pressure gauge, which should be made with a dead-weight gauge tester.

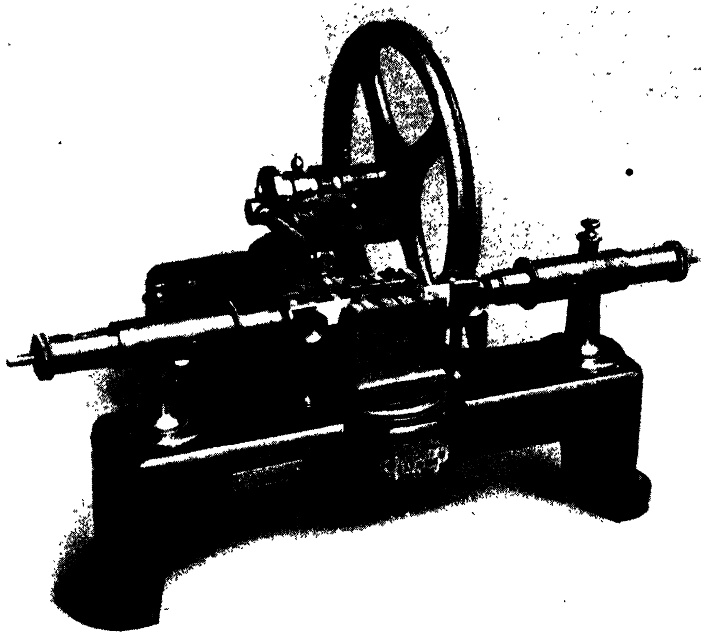


Fig. 7.

32. Folding Endurance.—A folding-endurance test is one of the best available criteria of the serviceability of paper that is creased or folded repeatedly, such as the types of paper used for correspondence and records. A brittle paper will fail quickly in this test, which measures the number of times a strip of paper can be bent around a very small cylindrical surface and back again in the opposite direction before the tensile strength is reduced to a

[1] Points per pound is the ratio of the bursting strength in points, as defined above, to the basic weight, and is sometimes called the **bursting factor**; when multiplied by 100, it is called the **bursting per cent.**

certain arbitrary value. The strip tested is usually 15 mm. wide, and the tension under which the strip finally breaks is usually 1 kg.

There are two designs of folding tester in fairly common use. In the one shown in Fig. 7, a reciprocating metal plate has a slot in it, bounded by two cylindrical surfaces half a millimeter (a fiftieth of an inch) in diameter, through which the strip of paper is threaded. The slotted plate carries the mid-portion of the strip between pairs of rollers in the back-and-forth motion, looping it snugly around the small cylindrical surfaces. This treatment of the strip amounts almost to folding it back on itself, first one way and then the other, while it is under tension. The tension is about 1 kilogram when the loop is fully formed, but is nearly a fourth less when the strip is straightened out.

In another design, provision is made for a constant tension. The two small cylindrical surfaces form the edges of the jaws of a lower clamp that holds one end of the strip, while an upper clamp fastens the other end to a spring that provides the desired tension. The lower clamp oscillates through a large angle about an axis that lies between and very close to the two small cylindrical surfaces, about which the strip is wrapped first one way and then the other.

There are also other types of folding testers less commonly used.

The calibration and adjustment of the first type of tester is not simple, and is sometimes very difficult. The calibration of the tension springs is made with dead weight, and is very much easier in the case of the second type. Results obtained with different types of folding testers do not bear a definite relation to one another, and they are not interconvertible, since the treatment accorded the strip is not the same in each case.

33. Tearing Strength.—Resistance of paper to tearing is most commonly measured by the average force required to continue for a fixed distance a tear already started. The instrument illustrated in Fig. 8 employs a sector-shaped pendulum, carrying a clamp that is initially alined with a fixed clamp to receive the specimen. The tear starts at the apex of a slit that is made on one edge with a special cutter attached to the instrument. The swing of the pendulum is retarded by an amount that measures

the work done in tearing the paper. For a fixed length of tear, the average force is proportional to the work done. Several plies of paper may be used to give a suitable reading on the scale.

Other tearing testers have been devised to measure the force required to start the tear, which is more significant in the use of paper, but these have not received much recognition.

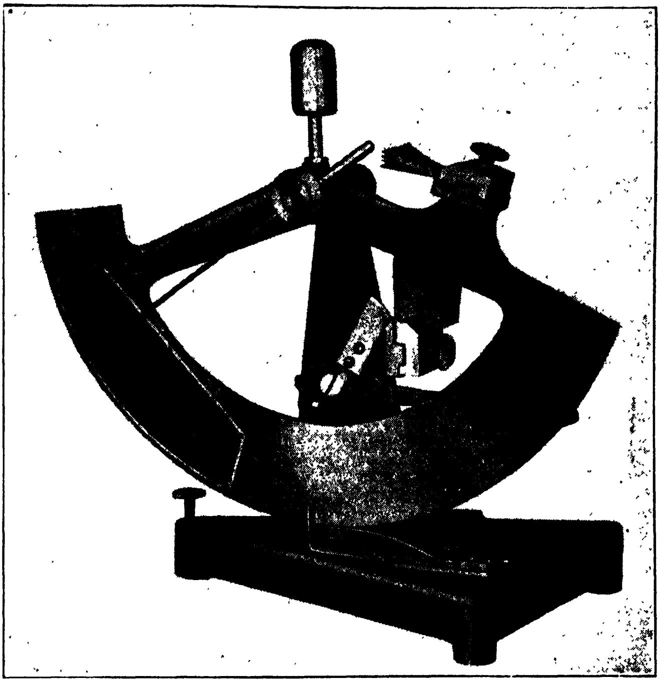


FIG. 8.

34. Stiffness.—The **stiffness** of a beam is ordinarily defined in terms of the force required to displace some reference point on the beam through a certain small distance within the elastic limit. Tests of the stiffness of paper, however, frequently bend the paper so much that it does not completely recover its original shape and size. There are several types of stiffness testers in use for testing paper and fiber boards. For the most part they define and measure stiffness in terms of: (*a*) the work done or the force exerted in bending a strip of given dimensions through a certain angle; or (*b*) the angle through which it is necessary to

bend the strip in order to do a certain amount of work or to exert a certain force at a designated point. The more common types measure the force or work by making the strip displace a pendulum as it is bent manually. The angle through which the strip is bent is defined in different ways in the different procedures. Another type of stiffness test measures the angle through which a strip of paper will bend under its own weight when supported in a specified manner. In such a test, neither the bending angle nor the bending force is fixed, except for papers of the same weight.

PERMEABILITY TO FLUIDS

35. Significance of Permeability.—Tests of the permeability of papers to fluids arise in determining the ability of blotting paper to absorb writing ink; of paper towels to absorb water; of printing papers to absorb printing ink; of wrapping and packaging papers to prevent the passage of oil, water, or water vapor; of sheathing papers to prevent the passage of air; of sized papers to prevent the rapid absorption of ink, water, or various aqueous solutions; and of various papers and fibrous sheets to perform similar offices.

36. Degree of Sizing.—A great many methods have been devised for measuring the property (or group of properties) variously known as degree of sizing, sizing quality, size fastness, ink resistance, water resistance, etc. The few tests for *degree of surface sizing* are qualitative, and they usually consist in observing whether characters written with ink remain sharply outlined or whether they 'feather.' The test is often supplemented by rewriting over erased characters. Another test that is sometimes used in judging the surface sizing and erasing quality of paper consists in drawing the paper across the surface of ink in a dish, allowing it to drain and dry, and examining it for uniformity of staining. A low-power microscope will show whether or not the fibers have absorbed the ink appreciably and uniformly. If the ink is erased from a portion of the sheet, and ink is again applied in the manner described, a paper with good erasing quality will show little evidence of increased absorption on the erased spot.

Most of the tests that have been proposed were intended to measure the *degree of internal sizing*, or the resistance the sheet

offers to the passage of water or an aqueous solution into or through it. A few methods of this type will be described.

37. Water-Resistance Methods.—Several methods are available for measuring the resistance that paper offers to the entrance of water. In one, a piece of paper is floated on water at a definite temperature, after a dry indicator powder has been sprinkled on the upper surface, and the time is measured from the contact of the paper with the water until color develops in the indicator powder. The indicator is powdered sugar containing about 2 per cent of a water-soluble dye, dried in a desiccator, and sieved through a 100-mesh screen before being mixed. A standard indicator of this type contains methyl violet as the dye and about 5 per cent of water-soluble starch as a stabilizer. The indicator is applied by sifting it through a disk of 100-mesh screen wire fastened in the mouth of a small bottle or vial, which is used as one would use a salt shaker.

An instrument has been developed that holds a part of a small specimen near one edge in contact with water at a definite temperature, while a longer, pointed portion of the specimen remains dry and serves as a pointer moving across a stippled background as the paper curls. The curling is caused by the expansion of the surface that is wet. When the water has soaked half through, the paper begins to uncurl, that is it begins to curl the opposite way. The instrument operates a stop watch to measure the time from contact with water until the curling reverses, which is the time required for water to penetrate half way through the paper.

In another method, the specimen, formed into a cup or fastened with wax to the end of a glass cylinder, is laid on a ground-glass surface, backed by a black surface. Water is poured on the upper surface of the specimen. The specimen is lifted periodically until one sees on the ground glass, where the specimen rested, a patch of moisture that quickly evaporates. The time required for water to pass through the paper is measured. This method is used more particularly for papers that are very resistant to water, such as asphalted papers.

A fourth method measures the amount of water absorbed through a given area of paper in a given time. The weighed specimen is held down in a horizontal position by a ring, into

which water is poured. After the lapse of a certain length of time, the water is poured off, that remaining on the surface is blotted off, and the specimen is weighed. The increase in weight is the amount of water absorbed in a given time.

38. Ferric Thiocyanate Method.—Several methods have been proposed in which there is applied to the opposite faces of a piece of paper solutions that interact to produce a color when they meet. In one of the best known of these, the paper is floated on a 2 per cent solution of ammonium thiocyanate, and a 1 per cent solution of ferric chloride is applied to the upper surface. The time until red specks of ferric thiocyanate appear all over the upper surface is measured.

39. Ink-Flotation Test.—Squares of paper are floated on writing ink at a given temperature, and the time required for the ink to soak through and appear on the upper surface measures the relative resistance of different papers to the transudation of ink. The end point, however, is somewhat indefinite, and the test serves poorly to measure the permeability of any liquid except writing ink; because paper has a certain affinity for the constituents of the ink that causes them to separate, and some to precipitate, resulting during the test in a continuous change of the character of both the paper and the ink that is passing through it. For this reason it is usually not possible to correlate the ink-flotation test satisfactorily with tests of the permeability of paper to liquids other than ink.

40. Electrolytic Methods.—Several instruments have been designed to measure the time of passage of an aqueous solution through paper by timing the change in an electric current that has been caused to pass through the sheet as an electrolyte soaks into it. In the different devices, the electrolyte ranges from a fairly concentrated salt solution to distilled water, and various forms of current detectors and meters have been used. The time is measured—usually with a stop watch—from contact of the electrolyte with the paper until the current has built up to a certain predetermined value. These methods, while fairly sensitive and reproducible, have found their chief use in mill control, since the results obtained seem to depend on the structure of the sheet, or some other factor that varies from paper to paper, in addition to the rate of penetration of the electrolyte.

41. Absorptiveness.—In contrast with sized paper, there are other papers and fibrous sheets that *absorb* liquids rapidly and in considerable amounts. Such materials as blotting paper, paper towels, and saturating felt are tested for rate of absorption, or for the amount of liquid absorbed at saturation.

42. Pipette Methods.—For testing blotting paper, 1 cubic centimeter of ink is flowed onto a 4-inch square of the material from a pipette whose tip is half an inch from the surface. The blotting paper is supported on a coarse wire screen that is slightly dished to induce the pool of ink to remain in the center. The screen may be supported by a beaker. The time required for the blotting paper to absorb 1 c.c. of ink is measured. When the sheen disappears from the wet surface the absorption is considered complete.

For testing paper towels, it is usual to flow a tenth of a cubic centimeter of water onto the paper from a small pipette, suitably graduated and supported at an angle of about 30° with the surface of the paper, so that the water will not flow out too fast to control. The tip of the pipette is allowed to remain in the pool of water until the required amount has been delivered; for if a drop-wise flow is attempted, the last drop may be too small to fall from the pipette. To facilitate this test, a special mounting has been devised for the pipette.

For testing very thin tissues, it is necessary to use a single small drop containing a hundredth of a cubic centimeter. Although some pipettes are graduated in hundredths of a cubic centimeter, it is difficult to deliver so small an amount accurately. Such a small amount can be measured from a capillary tube, and a microburette with special mounting has been devised to facilitate the dispensing of such small amounts of liquid. In this test, and also in that for paper towels, the time required for the paper to absorb the water is measured in the same manner as for the test of blotting paper for absorption of ink. Likewise, in both tests, the paper should be so supported that the part that becomes wet does not touch the support.

43. Strip Method.—Strips of blotting paper, or other absorbent paper to be tested, are so hung that one end of each dips into ink, water, oil, or other liquid, which then rises as in a wick. The height the liquid rises in a given time, say 10 minutes, is a measure of the relative absorptiveness. In some tests, particularly of the

absorption of oils and organic liquids, it is customary to measure the time required for the liquid to rise to a certain height.

In the case of ink the height is not sharply defined, because the ink separates into its constituents as it rises, and one will observe that the strip is wet somewhat above the colored part. The results will differ somewhat, depending on whether one judges the height of rise by the highest point that is wet, or by the highest point the color has reached. In this and other tests with ink, a standard ink is frequently required, although a good commercial writing ink is satisfactory for most comparative tests.

44. Blotting Tests.—Sometimes a practical blotting test is felt to be the only satisfactory way of judging the value of different blotting papers. To make the test reproducible, the same kind of writing paper, the same ink, and the same pen (preferably a stub pen) are used throughout, and the same characters, such as a signature, are written and blotted repeatedly. Small pieces of the blotting papers are employed, and the written characters are blotted in the same place on the blotting paper. The number of times each test piece will blot the written characters without smudging is a measure of the relative blotting value of that sample.

A mechanical blotting device is sometimes used, in which a drop of ink on a strip of writing paper is blotted by superimposing a strip of blotting paper and passing the two between a pair of rollers at a definite speed. The poorer the quality of the blotting paper, the longer will be the streak made on the writing paper by the ink.

45. Saturation Tests.—The most obvious way to test paper, felt, or board for the amount of liquid that it will absorb is to immerse a weighed specimen in the liquid at a definite temperature for a definite length of time, remove it, allow it to drain for a certain length of time, and reweigh. The increase in weight represents the amount of liquid absorbed. Sometimes the procedure is varied by allowing the liquid to enter from one side only, in an effort to prevent trapping of air in the structure; and sometimes the edges are sealed, since the absorption through the edges may proceed at a rate different from that through the face of the specimen. Another way in which the procedure is sometimes varied is to allow the liquid to run onto the specimen from a burette, the excess draining into a beaker. After saturation

seems complete, the difference between the amount of liquid originally in the burette and the amount left in it, together with that drained into the beaker, represents the amount absorbed by the material tested.

46. Absorption of Printing Ink.—For determining the rapidity with which paper absorbs printing ink, special methods are used. In one, a drop of castor oil is allowed to fall on the paper, and the time is measured until the portion of the paper under the drop has become saturated and appears uniformly translucent. No account is taken of the time required for the entire drop to be absorbed.

In another method, a drop of boiled linseed oil is allowed to fall on the paper, and is quickly spread out into a thin film by running a roller over it. The time is measured until the sheen that results from the absorption of the film of oil disappears.

47. Grease Resistance.—The resistance that paper offers to the passage of grease and oil is usually measured by the time required for the oil or grease to penetrate through the sheet. If the paper is opaque and not very resistant, the measurement can be made in a manner similar to the first method described for printing paper. Grease resistance in the most usual sense, however, refers to the ability of certain wrapping and packaging materials, usually transparent, to resist effectively the passage of animal and vegetable fats for a fairly long period of time. For the testing of such materials a different technique is required, thus: A very thin organic liquid, usually turpentine, is commonly used to hurry up the test, which is slow at best. As the test is ordinarily made, the material to be tested is laid on a piece of white paper, and the turpentine, preferably colored with an oil-soluble dye, is applied on the upper surface. Since the turpentine tends to spread and to run over the edges and underneath, it is retained, either by putting a little pile of sand on the material and saturating the sand with turpentine, or by means of a ring or cylinder cemented to the specimen with sirup or glue. Lead shot are used inside the ring to hold the specimen in contact with the paper underneath. The sand also serves the same purpose, but is less effective. The specimen is lifted periodically until stains appear on the underlying white paper, showing when the turpentine has gone through. Since the liquid passes through

such materials usually by going through imperfections, weak spots, or pinholes, the test may be varied by using clear turpentine, and shining lights alternately through the specimen from below and on it from above. Spots where the turpentine has gone through will appear alternately light and dark.

A test that is useful in comparing two wrapping materials consists in making a sandwich of the two materials with lard or some other fat between them. A piece of white paper is laid over the exposed surface of each, and the whole is held together under slight pressure between two glass plates. The poorer material will allow the fat to soak through first and stain the white paper.

Another method is frequently found useful in comparing several different samples. A fairly large specimen of each is made into a tray by turning up the edges all around. The specimen is then floated on a bath of some very thin organic liquid, such as gasoline or turpentine, that has been colored with an oil-soluble dye. Each specimen is so treated for the same length of time, after which the wet surface is rinsed off in some of the clear liquid. The color that has penetrated through the sheet with the liquid will remain, usually in spots, to show the relative amount of transudation. The pattern made by the colored spots, whether large or small, few or many, scattered or crowded together, will tell much about the characteristics of the different samples tested.

48. Water-Vapor Permeability.—The ability of wrapping and packaging materials to prevent the passage of moisture has been tested in several ways, the most common of which is to fasten a specimen over the mouth of a crystallizing dish containing some water or a drying agent, and to weigh the assembly at intervals after exposing under suitable conditions. If the dish contains water, it is exposed to a low humidity; if it contains a drying agent, it is exposed to a high humidity. The gain or loss in weight of the dish in a given time, after the rate of change in weight has become steady, is a measure of the rate at which water vapor passes through the material under those conditions. It is necessary to seal the specimen to the dish with wax in such a manner that no leakage can occur at the edges.

49. Air Permeability.—Several instruments have been devised to measure the rate at which air will pass through paper. In

all of them, air is forced through the paper by reason of a small difference in the air pressure on the two faces of the sheet, the pressure difference being held constant in some manner. In most of them, a measurement is made of the volume of air that is forced through a given area of the paper in a given time, or of the time required to force a given volume through the specimen. The volume of air is measured in some form of measuring flask or gasometer that is a part of the instrument. A stop watch is generally used to measure the time. In one type, the air that is forced through the paper is passed also through a calibrated capillary flow meter, and the rate of passage is determined from the manometer readings. In this type, the stop watch is not used, except in calibrating the instrument. Unless the material tested is thin and very permeable, special precaution is necessary to prevent some of the air from escaping around the clamp or through the edges, and not going through the specimen. The National Bureau of Standards has devised a precise instrument, in which a guard cell prevents edge leakage, and in which are incorporated other special features that enable measurements to be made with an uncertainty of less than half of one per cent.

SOME SPECIFIC EFFECTS OF CHANGE IN HUMIDITY

50. Magnitude of Humidity Effects.—The student has already been told that many of the physical properties of paper are very sensitive to changes in humidity; that some tests are almost meaningless unless made at a stated constant humidity; and that, in general, the tests described should be made at constant humidity after the paper had been conditioned. The student will have wondered how much effect a given change in humidity might have on the various tests, and having now become more familiar with these, he is in position to appreciate the specific effects.

The magnitude of the change in a property is not necessarily a good index of the practical significance of the change. The per cent change in the dimensions of a sheet with changing humidity is rather small; but a few thousandths of an inch change in two or three feet may be serious if it occurs between successive impressions in color printing: a hundred per cent change in some other property might not have an appreciable effect on the quality of the printing job.

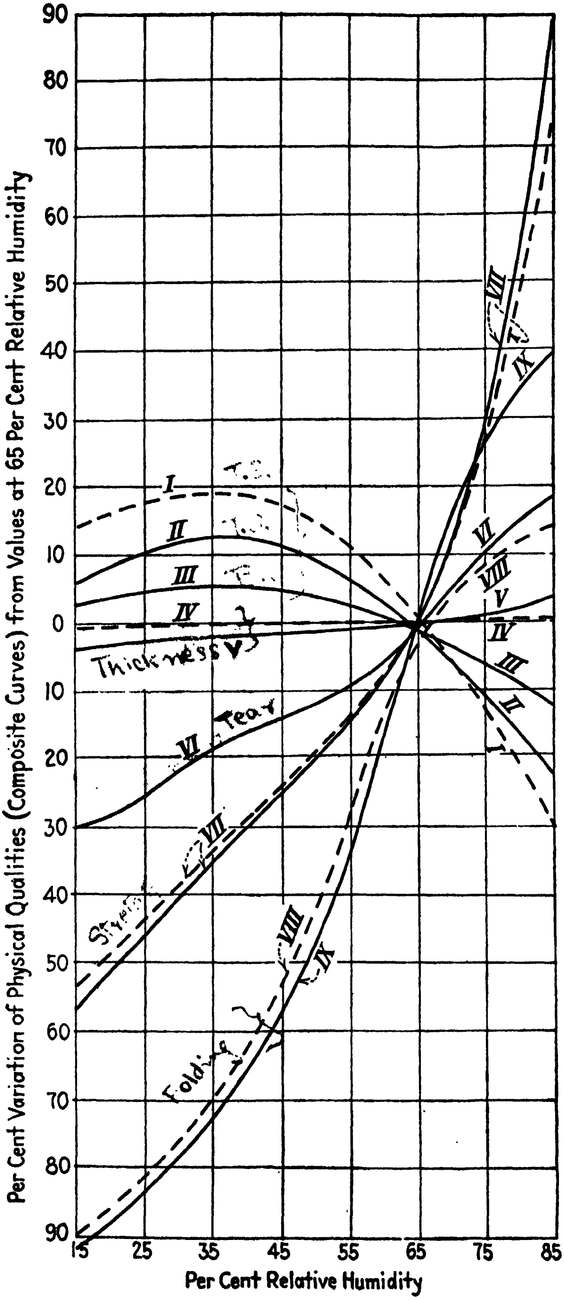

Per Cent Variation of Physical Qualities (Composite Curves) from Values at 65 Per Cent Relative Humidity
Per Cent Relative Humidity
90
80
70
60
50
40
30
20
10
0
10
20
30
40
50
60
70
80
90
15
25
35
45
55
65
75
85
I
II
III
IV
V
VI
VII
VIII
IX
Thickness
Tear
Folding

FIG. 9.

Humidity effects of the least significance probably occur in the group of surface characteristics and optical properties. Many of these tests are commonly made without regard to the humidity or to the moisture content of the paper. The tests of permeability to fluids are not very sensitive to humidity changes, although in most of these the paper should be conditioned at a constant humidity if accurate data are required. A paper, for example, that already contains some moisture will allow water to enter it more rapidly than will a dry paper, although it cannot absorb as much water as the latter. Some electrical properties of paper are very sensitive to humidity changes.

Changes in the dimensional and extension properties resulting from changes in humidity are not very great; but, as previously pointed out, a small change may sometimes have large significance, as in the case of expansion and contraction. The ream weight will change about in proportion to the change in moisture content, and the moisture content of paper will range from nearly nothing to about 20 per cent, depending upon the kind of paper and the relative humidity. Under standard conditions (65 per cent relative humidity at 70°F.) it will range from about 6 up to 10 per cent or so. Thickness will increase with increasing humidity, but most micrometers, or thickness gauges, are not sensitive enough to measure the change on a single sheet. If a number of sheets are measured together, the increase can be determined. In Fig. 9, the two curves (IV and V) lying close to the horizontal show the magnitude of the humidity effect in this group of properties.

The large humidity effects are found chiefly among the mechanical properties, as is strikingly revealed by the curves shown in Fig. 9. In this figure, the full lines represent the machine-direction behavior, and the dotted lines, the cross-direction behavior.

51. Effect on Tensile and Bursting Strengths.—Curves I and II, Fig. 9, are for tensile or breaking strength, showing an increase with increasing humidity up to about 35 per cent relative humidity, and thereafter a decrease. The total change over the humidity range shown is 20 to 30 per cent each way from the standard. The curve for bursting strength (III) is very similar, except that the change is less, being only 5 or 10 per cent. This is probably because the stretch acts in an opposite manner to the tensile

strength, and so that they tend to neutralize each other, since bursting strength depends on tensile strength and stretch in the machine direction. The stretch curves (VII) show a large increase with increasing humidity over the whole range shown.

52. Effect on Folding Endurance and Tearing Strength.—The effect of humidity on the *folding test* (curves VIII and IX) exceeds any of the other common mechanical tests, particularly in the lower humidity range. At very high humidities, it is exceeded by the effect on stretch. Folding endurance increases with increasing humidity over the whole range shown. There is some evidence that it may not continue to increase at very high humidities, as might be expected from the rapid decrease in tensile strength at high humidity.

Tearing strength (curve VI) also increases with increasing humidity over the whole range. The magnitude of the effect is comparable to that for tensile strength, although the total effect over the entire range is somewhat greater.

MICROSCOPY OF PAPER

INTRODUCTION

53. Bibliography.—Some of the more common uses of the microscope in the field of the paper industry will now be considered. As the "Bibliography on Microscopy of Paper," by Calkin, indicates, the use of the microscope is not confined to the examination of paper alone but is also applicable to a number of problems met by the technical man working in the field of paper. All too frequently the microscope is used only to determine the fiber composition of paper. Other uses are discussed herein, but space limits a more extended treatment of some subjects and requires the omission of others. The bibliography referred to above is quite complete, and it will serve as a guide to those wishing to make a more extended study of the subject, or to one desiring information on a particular part of it.

Before doing any extended work in the microscopy of paper, it is well to familiarize oneself with the general subject of microscopy. A knowledge of optics, general uses, and instruments available will save time and effort. These subjects are well treated by Gage ("The Microscope"), by Chamot and Mason

("Handbook of Chemical Microscopy," I and II), and in manufacturers' catalogs, to which the reader is referred for more detailed information than is contained in the following pages, Arts. **54–80.**

SIMPLE MICROSCOPES

54. Types and Magnifying Powers.—The principle of the simple microscope and magnifying glass was explained in *Elements of Physics*, Part 2, Vol. I. There are various types obtainable, among which are: (1) the reading glass, which consists of a double convex lens, with rather flat faces, and which has a long focal length; (2) pocket magnifiers, which contain from one to three lenses, in vulcanite, or other suitable, mountings, so arranged that the lenses can be used singly or in combination; (3) magnifiers known as doublets, triple aplanats, or aplanatic triplets. These last consist of two or more lenses, which are permanently combined in the same mounting; they have the advantage of clear, flat images, with large field, and great freedom from aberrations. Such magnifiers may be obtained in a variety of mountings, to render them suitable for use in a dissecting microscope or for carrying in the pocket, or they may be furnished with a handle for desk use.

Simple microscopes, of the types just mentioned, have magnifying powers of from 2 to 20 times (usually written $2\times$ to $20\times$, the sign of multiplication being read *times*). By this is meant that if the object were circular, it would appear to have a *diameter* from 2 to 20 times its natural size when viewed through the glass; and its area, of course, would be from $2^2 = 4$ to $20^2 = 400$ times its natural size. The magnifying power depends upon the focal length, which, in turn, depends on the degree of curvature of the lens; the greater the curvature, the shorter the focal length, the nearer the lens must be brought to the object, and the greater the magnifying power. In the case of the simple microscope, the magnifying power is computed by dividing 10 inches (the limit of distinct vision for the average person) by the focal length in inches. Thus, if the focal length is 0.8 inch, the magnifying power would be stated as $10 \div 0.8 = 12.5\times$. Or, if the focal length is given in millimeters, divide it into 250 millimeters. Thus, if the focal length is 20 mm., the magnifying power is $250 \div$

20 = 12.5×. For a shortsighted person, his limit of distinct vision would be less than 10 inches or 250 millimeters; it might be, say, 8 inches or 200 millimeters, in which case, the magnifying power of the glass to *him* would be only 8 ÷ 0.8 = 10× or 200 ÷ 20 = 10×. This method of finding the magnifying power applies only to the simple microscope; it cannot be used in the case of the compound microscope.

55. Spherical and Chromatic Aberration.—What is called **spherical aberration** is caused by the fact that the rays from the outer edges of the lens do not focus at the same point as those from near the center; the result is indistinct vision and a strain on the eye: it also makes a flat image appear convex. This may be largely overcome by reducing the diameter of the lens by grinding or cutting, thus making the lens take the form of a cylinder having convex ends.

Chromatic aberration is caused by the fact that each of the colors of the spectrum has its own wave length, and those having the shortest wave lengths are refracted more than those of longer wave lengths. This causes a sort of rainbow effect to appear around the edge of the magnified object. Chromatic aberration may be overcome by making the lens of two kinds of glass—crown glass and flint glass—which have different indexes of refraction.

A lens that has been corrected for chromatic aberration is called an **achromatic lens**; if corrected for both spherical and chromatic aberration, it is called an **aplanatic lens.**

56. Using Magnifiers.—Simple microscopes, or magnifiers, can be used only for work requiring comparatively low magnification; nevertheless, they are well suited to a wide range of work. For example, they may be used for examining all sorts of objects and materials that are too fine for the unaided eye, yet too coarse to necessitate the use of a compound microscope, such as: locating minute defects in the surface of papers; counting the mesh of finely woven wires; reading the graduations on precision thermometers and other instruments; examining shives and other foreign particles in paper, etc. To cover the varieties of work that these magnifiers are capable of handling, it is well to have at least two—an aplanatic triplet having a magnification of 20 diameters, and a pocket magnifier with three lenses. These two

instruments will fill practically all the needs of ordinary paper-mill work.

The manner of using these magnifiers depends more or less on the nature of the work in hand. In general, however, their use is so simple that no special directions are necessary. One suggestion is of particular value, and that is *always to keep both eyes open.* While, at first, the observer may be annoyed by objects seen with the unoccupied eye, he will soon find that they are completely ignored; and the consequent freedom from the fatigue caused by keeping one eye shut will enable him to concentrate more fully on the work he is doing. Also, the effort required to keep one eye closed produces a strain on the other eye, which impairs its vision.

COMPOUND MICROSCOPES

57. Principle.—The simplest form of a **compound microscope** consists of two double-convex lenses, one at either end of a tube. A diagrammatic representation of the passage of the rays of light through the instrument is given in Fig. 10. Here *ab* and *cd* are the lenses, and *mn* is the object. The lens nearest the object is called the **objective**; the other, the one nearest the eye, is called the **eyepiece** or the **ocular.** The principal focus of the objective is F and of the ocular is F'. It will be observed that the rays of light, after passing through the objective, cross one another and form an enlarged inverted image, called a **real image** MN, between the principal focus F' and the ocular; the ocular further enlarges this image by acting in the same manner as a simple microscope and forming what is called a **virtual image** of the real image. A real image is always *inverted*, but a virtual image is *direct*, *i.e.*, it occupies the same relative position as the object. The result of this is that the eye, which is situated at E, never sees the object; it sees, instead, an enlarged virtual image of an enlarged real image of the object. The eyepiece, or ocular, does not magnify as many times as the objective.

Examination of Fig. 10 will make it apparent at once that the shorter the focal length FO the greater will be the magnifying power of the lens *ab* and the nearer the lens must be brought to the object. Unfortunately, however, the greater magnifying power of *any* microscope the less is the amount of light available

for the eye; consequently, for high magnifications, it is necessary to provide some means for increasing the strength of the light. This last is accomplished by means of a mirror or by the use of a condenser, which concentrates rays of light on the object.

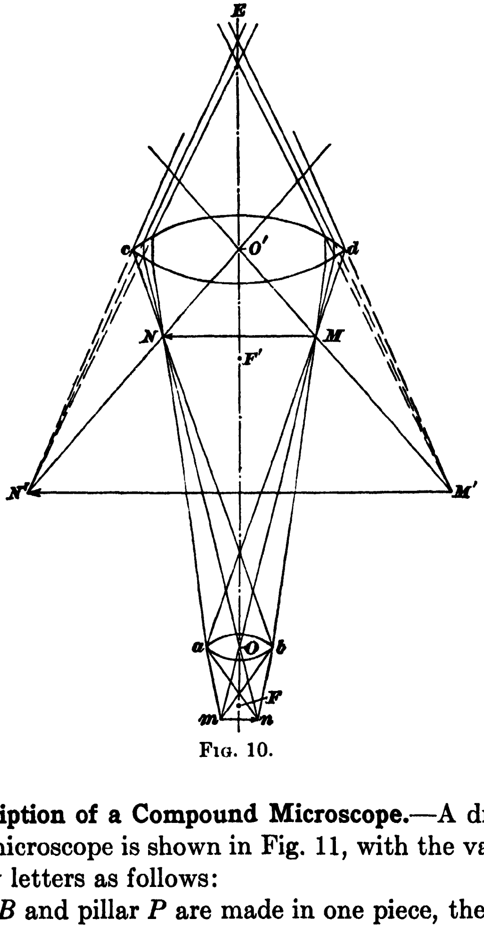


Fig. 10.

58. Description of a Compound Microscope.—A drawing of a compound microscope is shown in Fig. 11, with the various parts indicated by letters as follows:

The base *B* and pillar *P* are made in one piece, the base being made very heavy and rigid, to give stability to the instrument. As shown here, the microscope is in a vertical position; but it may be inclined to any position between the vertical and the horizontal, to suit the conditions of the work, by swinging the arm *A* backward, turning on the joint *I*. The arm *A* carries every part of the instrument except the base and pillar; and it is of such

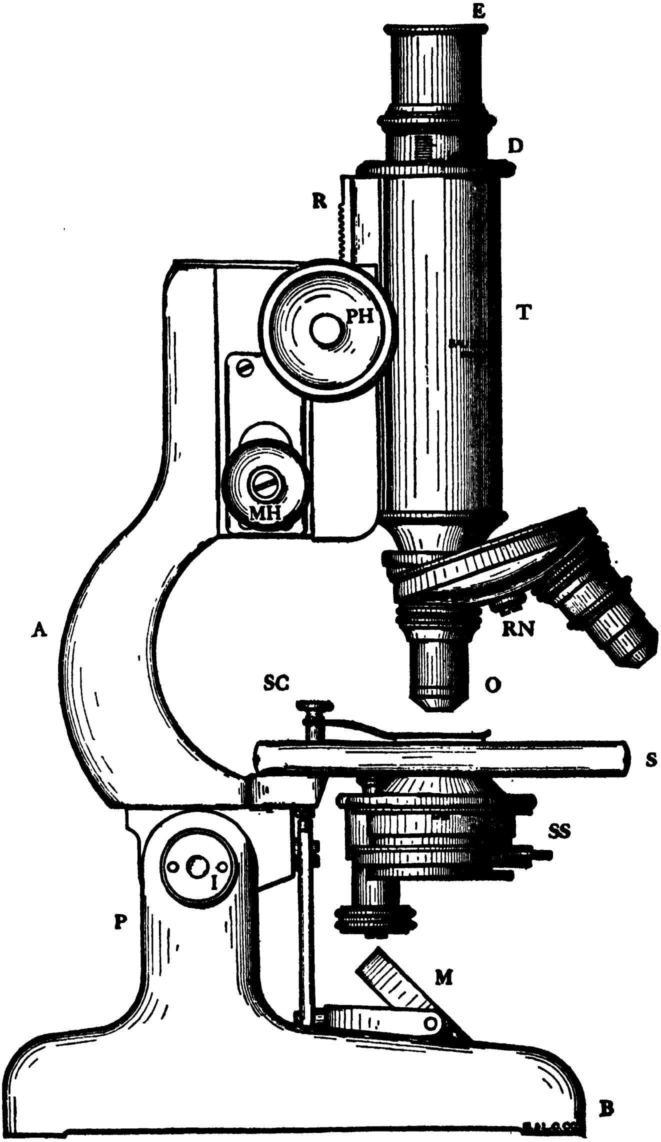


Fig. 11.

shape as to make it a convenient handle for moving the microscope from place to place. The body tube *T* carries the rack *R*, which enables the tube to be moved up and down quickly by turning the pinion head *PH*; this is called the *coarse adjustment*, and it affords a means for obtaining a rapid, though approximate, focus. The micrometer head *MH* gives the *fine adjustment* and completes the focusing. The body tube *T* has screwed into its lower end the objective *O*. In many instruments, as in the present one, the body tube has attached to it what is called a *nosepiece*, which carries two objectives (sometimes three or even more), one of high power and the other of lower power. The nosepiece revolves on the pin *RN*, and either objective can be brought almost instantly into position. At the other end of the tube *T* is the draw tube *D*, which has a sliding fit in *T*; it fits tube *T* so tightly that it will remain in any position. The upper end of the draw tube carries the eyepiece, or ocular, *E*. The draw tube is graduated for a part of its length in millimeters, so the distance between the ocular and the objective can be accurately determined; this distance is called the *tube length*. The standard tube length for which most objectives are corrected is 160 mm., and this may be obtained by pulling out the draw tube until the 160-mm. mark just shows, as indicated in the illustration; but because lenses have different thicknesses, the tube may require a slight adjustment above or below this mark. The stage *S* is a platform on which the objects to be examined are placed. Some objects are so small that they are mounted on glass slides; this means that they are placed on *glass slides*, to which they are stuck by a little Canada balsam, a transparent resin that has the same index of refraction as glass. The slides are held in place by the spring clips *SC*. Under the stage, and attached to it, is the substage *SS*, which contains an Abbe *condenser* and a *diaphragm;* the latter regulates the size of the opening through which light is transmitted from the mirror *M*. The stage has a hole through it directly under the objective, and the glass plate covers this hole. The mirror can be adjusted to any angle, and it can be revolved so that the middle plane can also make different angles in the cross direction; hence, no matter what the direction of the light, the mirror can be so adjusted as to direct the light along the axis of the tube *T*. The condenser is fitted with a lens, which concentrates on the object the light transmitted from the mirror.

One side of the mirror is plane, and the other is concave; the plane side is used with the condenser, and the concave side is used when the condenser is removed. Of all the parts here enumerated, the absolutely essential ones are the objective *O*, the eyepiece (ocular) *E*, and the illuminating devices *M* and *SS*.

59. The Objective.—The purpose of the objective is the formation of an enlarged real image of the object being examined, while the eyepiece magnifies this real image and, at the same time, collects light rays that increase its brilliancy.

Objectives are generally designated by their **equivalent focal length,** which indicates that the image produced by the objective will be approximately the same size as that produced by a single convex lens whose principal focus is at the distance marked on the objective. For similarly constructed objectives, the smaller the equivalent focus the greater the magnifying power.

Objectives are corrected for spherical and chromatic aberrations, the degree of these corrections determining the purpose for which the lens is best suited. For very exacting work, these factors must be carefully considered; but for most paper-mill work, they need cause no worry. Objectives are also corrected for a cover-glass thickness of 0.18 mm. (see Art. **69**), which is the average thickness of a No. 2 cover glass. For all but the very highest magnifications, two objectives of 16 mm. and 4 mm. equivalent focus will be found to be sufficient.

60. The Eyepiece.—Eyepieces are designated either by the number of times they magnify the real image or by their equivalent focal length. The light rays leaving the eye lens of an ocular are concentrated in a small circle, known as the *eye point*, situated at *E*, Fig. 11; this is the proper position for the eye of the observer.

61. The Condenser.—Condensers are not absolutely necessary when objects are to be examined with low powers by transmitted light (see Art. **76**); but when even moderately high powers are used, and the object is one of fine structure, some form of substage condenser is essential. In fact, unless exceptionally low powers are to be used, it is always a safe proceeding to use the substage condenser. The plane side of the mirror should be used with it, although the concave side may be used if the dia-

phragm is closed two-thirds or more and the condenser is lowered somewhat. Condensers may be caused to give oblique illumination by dropping a half circle of black paper or cardboard on the swing-out ring that is attached to the bottom of the condenser mounting.

62. Binocular Microscopes.—The usual form of microscope permits the use of only one eye; but with the binocular microscope both eyes may be used. Instruments of this type have two body tubes, fitted with carefully matched pairs of objectives and oculars. In addition to the advantage of using both eyes, binocular microscopes give stereoscopic effects, which cause the object to stand out in relief; but they are not efficient for magnifications exceeding about 100 diameters.

63. The Work Bench.—To avoid fatiguing the worker, the table or bench at which the microscopic work is to be done should be of the correct height. It should be so placed that it is as free as possible from vibration and subject as little as possible to drafts: the latter may deposit dust upon the work in hand, thus interfering with the observations. The top of the bench should be of close texture, and should be finished, preferably, in dull black. A very satisfactory top may be made from whitewood, stained with aniline black. A shiny or polished surface should be avoided: the reflections from it will tire the eyes.

The bench should be so located that the worker may, if possible, face a north light; but it should not be placed where it will receive light reflected from brick or other highly colored walls. To protect the microscope from acid fumes, it is desirable that the bench at which it is used should not be in the main laboratory; but, for convenience in working, the room containing it should be fitted with water, gas, and a sink, or the bench should be placed where these are readily accessible. The bench should be fitted with one or more drawers, to keep accessories in; it should also have shelves, for reagent bottles, stains, etc.

64. Sources of Light and Illumination.—For such work as the paper-mill chemist is called on to perform, the best light is obtained from a window that faces the north when the sky is uniformly, but lightly, clouded. For most of his work, the light will be used either axially transmitted *through* the object or

reflected obliquely from it, the latter for certain observations when low-power objectives are used.

When using artificial illumination of a yellow character, blue glass should always be placed below the condenser. Most microscopes are supplied with a blue-glass disk, for use with the Abbe condenser.

The proper illumination of the specimen to be examined is fully of as much importance as the selection of the correct combination of objective and ocular, and the more attention that is given to this subject the better will be the results obtained. A very common fault is the use of too much light, since this renders it impossible to see many of the details of the object. It is possible to overcome this difficulty by lowering the Abbe condenser and then closing its iris diaphragm to a diameter that is about two-thirds the diameter of the rear lens opening of the objective; this may easily be done by removing the ocular and, while looking through the tube of the microscope, closing the diaphragm until the disk of light is reduced to about one-half or two-thirds. This same method of observing the lighted field after removing the ocular will enable the light to be properly centered, so that uniform illumination may be obtained.

65. Focusing.—After the illumination has been properly adjusted, the object may be placed on the stage, and the focusing begun. Holding the head to one side, lower the tube until the objective nearly, but not quite, touches the object. Then, looking through the ocular, raise the tube by turning the pinion head *PH*, Fig. 11, until the object becomes plainly visible. Complete the focusing, for observation of the finest details, by means of the micrometer head *MH*. While, with low-power objectives, say up to 16 mm., it is fairly safe to *focus downward, i.e.*, while looking through the ocular, it is best not to do this, since one is liable to break the cover glass; and this should *never* be attempted when using high-power objectives, or even with low powers if the object is so transparent as to be difficult to see.

66. Care of the Microscope.—The chief rules to be observed in caring for a microscope may be stated as follows:

(*a*) When not in use, always keep the microscope in a dry place, protected from dust, and where it will not be subjected to sudden changes in temperature.

(*b*) Keep all parts clean and free from dust; never allow any of the fluids used in mounting or any chemical reagents to come in contact with any part of it.

(*c*) All movable parts should be cleaned occasionally by the use of a little xylol on a soft cloth; after which, they should be lubricated with a little vaseline.

(*d*) Objectives may be cleaned by wiping with new, clean lens paper; they should not be touched with the fingers or with cloths.

(*e*) Dust on the back lens combination may be removed with a camel's-hair brush.

(*f*) Oculars should be given the same care as objectives.

(*g*) When carrying the instrument, hold it by the pillar, or support it with the fingers under the stage.

MICROSCOPE ACCESSORIES

67. Slides.—**Slides** are made of thin, clear glass, free from defects, and are generally 1 inch wide by 3 inches long; they are used to hold the objects to be examined, which should be spread out thinly and uniformly, so that all portions of the material may be readily visible under the microscope. The slides may be of colorless or of greenish glass, the latter generally being more resistant to chemical reagents. Their edges should be ground smooth, and, for convenience, they all should be as nearly as possible of the same thickness.

68. Slide Boxes.—Slide boxes, or containers of some sort, are required for keeping clean slides ready for use and for holding permanent mounts. There are many different forms of these containers, ranging from simple trays that hold a few slides up to cabinets that hold hundreds. For most purposes, wooden slide boxes, about $6\frac{3}{4} \times 3\frac{1}{4} \times 1\frac{1}{2}$ inches, holding 25 slides each, will be found satisfactory.

69. Cover Glasses.—**Cover glasses** are very thin pieces of glass, which are placed on the slide over the object or specimen to be examined. They serve to flatten and protect the object, and they also keep the fluid mounting medium in place. Cover glasses may be obtained in either circular or rectangular form, and of varying sizes and thicknesses; they should be made of good glass, and should be as free as is possible from bubbles or surface irregularities. When working with high magnification,

the thickness of the cover glass has a marked influence on the definition (clearness of outline) obtained; and differences in thickness of 0.05 mm. (0.002 inch) may give very different results. If the objectives used have been corrected for cover glasses of some particular thickness, usually 0.18 mm. (0.007 inch), it is well to measure the thickness of all those on hand, setting aside those of the required thickness for use with these objectives. For most of the work connected with paper, a thin slide can be substituted for the more fragile cover glass; but for high magnifications, cover glasses of the required thickness are absolutely essential.

70. Forceps and Needles.—For handling small samples, lifting cover glasses, etc., forceps will be found to be very desirable. A convenient type is about 4 inches long, with fine, curved points.

Needles are very necessary in microscopic work for arranging objects on the slides, for teasing out fragments of material, for separating fibers, etc. They may be bought from dealers, mounted in wood or bone handles; but these are not entirely satisfactory, because the handles are easily broken and do not always hold the needles securely. A very satisfactory substitute may be made by forcing a stout sewing needle, eye first, into a handle whittled from a small piece of soft wood.

71. Test Tubes and Bottles.—Test tubes are used for preparing samples of paper for examination and for numerous other operations. A convenient size is a tube about ¾ inch in diameter and 6 inches long; a few tubes of a smaller size should also be provided, to handle very small samples of materials that occasionally have to be examined.

Bottles for holding stains and microscopic reagents should preferably be uniform in size and shape. The so-called *dropping bottles*, which are fitted with ground-in dropping tubes and rubber bulbs, are very convenient. However, a good substitute can be made from small bottles and a good grade of cork stoppers, with holes of the proper size bored through the corks, and ordinary medicine droppers inserted in them.

72. Micrometers.—Micrometers are used for measuring objects examined under the microscope. The more common type of eyepiece micrometer is one whose scale graduations consist of rulings of equidistant spaces. This scale is so placed as to fall

in the same plane as the real image formed by the microscope; it therefore really measures the size of the image, not that of the object. Consequently, to obtain actual values, it is necessary to compare the *eyepiece micrometer* with a *stage micrometer* for each objective used. The stage micrometer generally consists of a glass slide, upon which is ruled a 1-mm. line divided into 100 equal parts. This is so placed on the stage of the microscope that the center of the rulings falls in the center of the field. After focusing carefully, the micrometers are adjusted by turning one or both until the rulings of one scale are parallel to those of the other. The stage micrometer is then moved until one of its lines coincides with a line on the eyepiece scale, and the number of divisions of the latter that are included between two or more consecutive divisions of the stage micrometer are counted. Divide the value of the stage scale by the divisions of the eyepiece scale, as found, and the quotient will be the true value of the eyepiece scale. It is obvious that any change in the length of the draw tube or in the objectives will change the value of the eyepiece scale. After determining the true value of the eyepiece micrometer, the object to be measured is placed on the stage, and the number of divisions of the eyepiece scale that it covers is read; this result multiplied by the value per division will give the true size of the object.

73. Polarizing Apparatus.—The use of polarized light, (see Art. **78**, is occasionally very desirable, particularly when starches, crystals, and mineral substances are to be examined. The apparatus ordinarily employed consists of two Nicol prisms, Art. **80**, one of which is placed below the stage and the other above the objective of the microscope. For the methods employed and the results obtained by the use of polarized light, reference must be made to some of the textbooks describing the applications of polarized light to microscopical investigations; the scope of this work is too limited to permit of a detailed description and explanation.

74. Drawing Cameras.—A drawing camera, or **camera lucida,** is a device that may be attached to the tube of the microscope, to enable the observer to see the specimen on the stage and a sheet of paper simultaneously. He is therefore able to trace on paper the outline and many of the details of the preparation

(specimen) as magnified by the microscope. There are many types of these devices for sale, some of which are comparatively inexpensive.

75. Photographic Cameras.—Photographs taken through the microscope are very useful for comparisons and for permanent records, since they usually show conditions much more plainly than any amount of description. There are many types of photomicrographic outfits, but the majority are relatively expensive. An ordinary camera, placed in line with the microscope while the latter is in a horizontal position, can be made to do excellent work; it is well worth trying if a better equipment is not available. The selection and proper manipulation of the photomicrographic equipment cannot be discussed here, for lack of space; and the interested reader is referred to textbooks dealing with this subject.

76. Microtomes.—Most of the investigations made with the microscope are made with *transmitted light;* that is, the light is transmitted *through* the object, instead of the object's being viewed by *reflected light,* as in ordinary vision. In the case of a solid object, this necessitates that the specimen be a very thin *slice,* which must be of even thickness and homogeneous. Special instruments, called **microtomes,** are used for preparing these slices, the thickness of which is determined by the graduations on the scale of the microtome, and which usually average from 0.03 to 0.04 mm. (0.0012 to 0.0016 inch). In paper-mill work, such instruments are seldom needed, although one might occasionally be required in research investigations. For ordinary, simple work, a section razor, flat on one side and concave on the other, will fill the wants of most microscopists, and excellent work can be done with it after a little practice.

77. Illumination.—For best results in microscopic work, a clear north light is desirable and is to be preferred. However, where there is a large amount of routine testing to be done, it is advisable to have a more constant source of light. There are various types of lamps available, but good results can be obtained with a common 50-watt lamp in conjunction with a blue 'daylight' filter. It is to be noted that the color of the stained fibers on the slide will be somewhat different for the two kinds of illumination.

POLARIZED LIGHT

78. Definition of Polarized Light.—In *Elements of Physics*, Part 2, Vol. I, it was stated that light was transmitted by the movement of particles of the ether in a direction transverse (at right angles to) the direction of the ray. All the particles in the

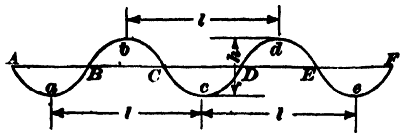


FIG. 12.

neighborhood of the line indicating the direction of the ray, this line passing through the center of disturbance, are set in vibration; and any plane passed through this line, whether vertical, horizontal, or making any angle to either, will give a curve on this plane, the shape of which will resemble that shown in Fig. 12, in which the distance h is the amplitude of the wave. Here AF, the line through the center of disturbance, is the direction of the ray of light, which may be supposed to be from A toward F.

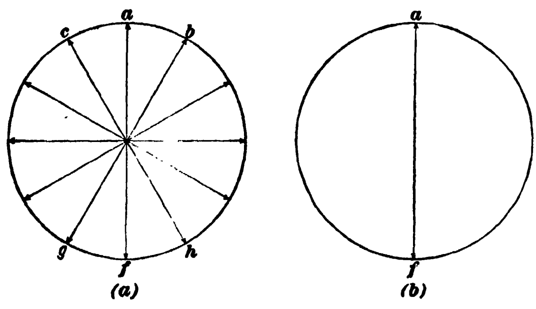


FIG. 13.

The projection of these wave outlines on a plane perpendicular to AF will be a series of (infinite number of) lines af, bg, ch, etc., as shown at (a), Fig. 13, where af may be considered to be the projection of the wave AF, Fig. 12. The lengths of these lines, which are all equal, of course, may be considered to be the amplitude of the waves; and the cylinder thus formed, whose diameter is the amplitude of the wave and whose length is the length of the ray, may be regarded as the part of the ether disturbed by the

passage through it of this ray of light. Such light, called **ordinary light,** thus vibrates in all planes transverse to its direction.

If, however, the character of the ray of light can be so altered as to make it vibrate in *one* plane, as indicated by *af*, in (*b*), Fig. 13, such light is said to be **plane polarized.** This plane may make any angle with the vertical, but, for convenience, is shown here as a vertical plane.

79. Polarization by Reflection and Refraction.—Referring to Fig. 14, let *AB* represent several flat, thin glass plates, and suppose a ray of light (ordinary light) *ao* to strike the plate at *o*;

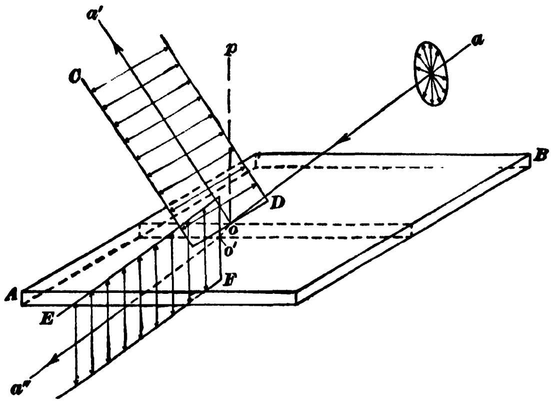


FIG. 14.

it is reflected in the direction *oa'*. Also, as it passes through the plates, it is refracted to *o'*, and emerges in the direction *o'a''*. All three rays, the incident ray *ao*, the reflected ray *oa'*, and the refracted ray *oo'a''*, lie in the same plane. The reflected ray *oa'* is polarized, either partially or wholly, in the plane *CD*, which is at right angles to the plane of the three rays; the refracted ray is also polarized, either partially or wholly, in the plane *EF*, which coincides with the plane of the three rays. If the ray of light be made to strike the plane *AB* in such a manner as to make various angles with the perpendicular *po*, the degree of polarization will vary, becoming a maximum for ordinary glass when the angle *aop* is 57°; the angle formed by the intersection of the reflected and refracted rays *oa'* and *o'a''* will then be 90°.

Polarization by reflection or refraction is not complete enough for the finer scientific investigations; but it can be totally polar-

ized by other means than those just described, as by the use of **Nicol prisms,** or **nicols,** as they are commonly called.

80. Nicol Prisms.—Nicol prisms, or nicols, are made from calcite crystals (Iceland spar). Iceland spar has the peculiar property of what is called **double refraction;** that is, the incident ray is split into two rays, called the *ordinary ray* and the *extraordinary ray.* While both these rays are refracted, the ordinary ray is refracted more than the extraordinary ray; also, their planes of vibration are at right angles to each other, both rays being polarized.

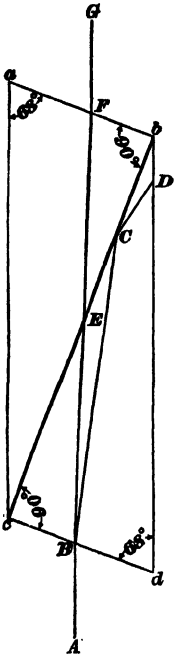


Fig. 15.

The prism is constructed as follows, referring to Fig. 15: The ends of the prism are cut parallel to each other at an angle of 68° with the sides *ac* and *bd*, as shown. The prism is then cut into two equal parts, along the short diagonal *bc*, which makes an angle of 90° with the ends; this, of course, limits the length of the prism; *i.e.*, the longer is *ab* = *cd* the longer is *ac* = *bd*, and vice versa. The two halves are cemented together with Canada balsam, which has almost exactly the same index of refraction as the extraordinary ray. Let *AB* be a ray of ordinary light, striking the end *cd* at *B*. Here it splits into the two refracted rays, the ordinary ray *BC* and the extraordinary ray *BE*. The extraordinary ray is only slightly refracted; it passes through the Canada balsam with practically no further deviation and emerges as the totally polarized ray *FG*. The ordinary ray *BC* is refracted more than the extraordinary ray *BE*; it also is polarized, and the plane of its vibrations is at right angles to that of *BE*. Calcite is a much denser medium than Canada balsam for light having a plane of vibration corresponding to that of the ordinary ray; and, since this ray impinges on the layer of balsam with a sufficiently high angle of incidence, it is totally reflected along *CD* and lost. A Nicol prism thus produces light that is polarized in only one plane.

The limits of this work preclude further discussion of polarized light and the polarizing microscope; for further information, the

student is referred to works on mineralogy, petrography, and microscopy.

TESTS WITH MICROSCOPE

81. Microscope Requirements.—A microscope to be used only for routine fiber analysis should be of the compound type, with a magnification of not less than 100 diameters. This may be obtained, with the draw tube at 160 mm., by using a 10× eyepiece and a 16-mm. objective. Some manufacturers do not use this nomenclature; hence, the manufacturer's instruction book should be consulted. A mechanical stage greatly facilitates the making of fiber analyses. Higher magnifications and such accessories as a condenser, Nicol prisms, dark-field illuminator, etc., often facilitate the identification of fibers. The square or rectangular stationary-stage type of microscope is probably that most common used; it is cheaper than the other types, and is carried in stock by instrument makers. The chemical microscope is a more useful instrument, as it has a wider application for laboratory problems. Differences in design characterize this type of microscope, which is carried by various manufacturers. There is a wide range of microscopes applicable to fiber analysis; hence, before purchasing a microscope, it is advisable to bear in mind the other types of work for which it is to be used.

SPECKS AND SPOTS IN PAPER

82. Accessories and Chemicals.—The accessories and chemicals for the identification of spots should consist, for general purposes, of a set of dissecting needles, a platinum needle (made by fusing a piece of platinum wire in a glass tube or rod and then sharpening the platinum point), a magnetized needle, carbon tetrachloride, ether, benzene, dilute hydrochloric acid, and solutions of potassium ferrocyanide and of litmus or methyl orange. Unusual spots require more extensive tests in chemical microscopy.

The source of many spots in pulp and paper depends, to some extent, on the type of raw material being used in the mill. Anyone doing this type of analysis should be on the watch for peculiarities, as almost any foreign material may be found. However,

the general types of spots that may be encountered are the following.

83. Alum Spots.—These are usually pulverized by the pressure of the calender rolls. They are soluble in water, and give a slightly acid reaction with indicators.

There is one type of speck, caused by the alum in the stock reacting with the fresh water from the showers, which does not seem to be generally recognized. The material is deposited on the showers and on the wire, and it occasionally breaks off apparently from the showers but not from the wire. The particles vary in color from a light brown to a green, the latter being due to copper from the screens. The material is quite brittle, and under the microscope it is clear and looks as if it might be crystalline. However, it shows no double refraction. It is insoluble in the organic solvents, but dissolves readily in hot dilute hydrochloric acid, and gives a strong test for aluminum. It is probably one of the hydrates of aluminum.

84. Bark Specks and Bleach Scale.—**Bark specks** are more easily identified in wood pulps than they are in paper. The speck is readily disintegrated into brown particles by slight pressure with a needle. Because of the pressure of the rolls, these spots in paper tend to be considerably broken; but they can usually be differentiated from coal or cinders by the fact that they are brown instead of black, and by their behavior on a hot crucible lid.

Bleach scale, a pearly light-brown brittle spot, is detected with dilute hydrochloric acid, which causes effervescence of carbon dioxide.

85. Bronze Specks.—They may be picked up from piping, from the beater, or from the press rolls. They are frequently identified easily by their shiny appearance. For some reason, apparently not fully understood, bronze specks may also occur as a dendritic growth, which is characteristic and has become known as a 'bronze-fleck.'

Bronze is identified by the red copper reaction when hydrochloric acid and potassium ferrocyanide are added to the spot. Certain types of bark specks may be confused at times with bronze from this reaction, but tend to have coarser particles than the precipitate formed by the above reaction.

86. Button Specks.—Buttons, ground by beaters or Jordans into small pieces, appear in the finished sheet. These may be bone, pearl (shell), or hard rubber. The first two often make a hole, owing to the particle piercing the sheet and then partly crumbling out after calendering. Such specks can be differentiated from alum, as they are insoluble in water and give no color reaction with indicators.

87. Cinders and Coal Specks.—These are insoluble, and give no color reaction with any reagent: in appearance, iron scale may be mistaken for these. The specks are sometimes hard and sometimes brittle; but can be easily identified by the use of a magnetic needle, as they are, of course, non-magnetic. Under the microscope it can be seen that these particles in a calendered sheet have been so pulverized by the pressure of the rolls that they shatter very easily when picked with a dissecting needle. Large particles give a characteristic black smear when crushed and rubbed across the sheet.

88. Color Spots.—Poorly ground colors give a fine, specky appearance, usually identified only by color.

89. Drag Spots.—Stock adhering to the slices on the wire forms small uneven lumps when it drags off upon the sheet. These spots are not very common, but can be recognized as irregular formations having no foreign material present.

90. Felt Hairs.—Wool hairs from felts sometimes occur on the surface of paper: they can be identified by the usual characteristics of wool.

91. Foam Spots.—Because of the depression left after each foam bubble, there is a circular spot, more translucent than the rest of the sheet, formed wherever foam bursts on the partly formed sheet. The result is characteristic, the spot being circular and translucent, similar to a small round watermark. Foam spots often contain a larger amount of filler than the part of paper around them.

92. Iron Specks.—Washer or beater bars, Jordans, scaly pipes, corroded overhead ironwork, and iron buttons from rags, contribute iron in metallic or oxidized forms, at times. If the metallic particles are free from the sheet, they will be attracted by a magnetic needle.

The scale or oxidized iron can be identified (except Fe_3O_4, which is insoluble in HCl and must be reduced with stannous chloride $SnCl_2$) by adding a drop of dilute HCl, followed by a drop of potassium ferrocyanide $K_4Fe(CN)_6$ solution. Iron gives a characteristic blue color.

Instead of identifying the iron under the microscope, it is possible to determine which specks are iron by immersing the paper in dilute HCl, followed by dipping it in a dilute solution of $K_4Fe(CN)_6$. There will be a blue coloration wherever there is an iron speck in the sheet (excluding, of course, the insoluble Fe_3O_4).

93. Knots.—In rag stock, fabrics with knotted threads very often show the knots in the finished sheet. The knotted thread is easily recognized under the microscope.

94. Oil Spots.—Oil spots are translucent, and can be spread or thinned with ether or carbon tetrachloride CCl_4. Extraction with either of these solvents removes the oil, unless it is of a peculiar pasty formation caused by the use of oily rags in the stock. Mineral oil in rags is prone to form a dirty, congealed mass in the washers, which spots the half-stuff with black specks, in which the mineral oil is the binder. Such specks in the finished sheet are not entirely removed by ether or CCl_4. They are slightly translucent, and unaffected by solution in concentrated sulphuric acid H_2SO_4.

95. Paper Specks.—In stock made from old papers, or where broke has been added, small undefibered pieces may slide through the screens and form specks on the sheet. Such specks are fibrous; and when lifted out of the sheet, they can be defibered under the microscope with dissecting needles, showing their identity by this characteristic.

96. Resin Specks.—The sources of this type of speck will be twofold: they may come from wood pulp, the number depending on the resin content of the wood and the type of cooking; the same type of specks may also come from the incomplete saponification of resin for sizing. They are usually translucent, amber-colored specks, which may be further identified by the fact that they are soft and punky when pressed with a fairly blunt needle; they are also flattened out by this treatment, and sometimes tend to stick to the needle. Owing to the type of resin or to dirt that

has been picked up, they are sometimes dark colored. The dirt that is picked up sometimes consists of iron, and can be identified accordingly. Resin specks are sometimes soluble in ether, but there are forms which have been so changed in the process that they are almost completely insoluble. When touched with a hot needle, a characteristic odor may often be detected.

97. Rubber.—This finds its way into the stock with rag half-stuff and old papers, sometimes as rubber paste in tire fabrics—tags containing elastic and the like—and sometimes in old paper stock as rubber bands from office waste. The best characteristics for the identification of rubber is that it swells in benzene, and that it dissolves in CCl_4. The rubber specks will give a characteristic odor if burned by sticking them into a flame on the end of a needle, or by touching with hot needles.

98. Shives.—Shives may result from incomplete cooking or screening of wood pulp, the accidental grinding off of a beater paddle, or from some similar cause. They can be identified as fibrous bundles, but it is sometimes advisable to dissect them with needles. They will give a red coloration on the application of phloroglucinol solution.

FIBER COMPOSITION OF PAPER

99. Importance of Fiber Analysis.—Fiber analysis of paper is of importance from the standpoint of (1) the mill, (2) the consumer, and (3) the Courts. From the standpoint of the mill, a customer sends in a sample of paper, and before running the paper it is often necessary to know what the furnish is. Then, too, a mill may be buying old papers, and here it is important to know the fiber composition. From the consumer's point of view, he may wish to determine whether the paper purchased is up to specification for fiber content. Many industries have agreements to furnish certain grades of paper or paper products of a certain quality, and one of the specifications may be fiber composition. In the case of the Courts, the fiber composition may identify the date of a sheet of paper (*i.e.*, when a fiber was first produced), its source, or its identity with another sheet.

As before stated, the microscope finds its most extended use in the paper laboratory for the determination of fiber com-

position. Various attempts have been made to supplant or supplement the microscope by chemical analysis (*cf.* Calkin, "Bibliography on Microscopy of Paper"), but chemical analysis has only found a narrow application; *e.g.*, in certain instances for sulphite-groundwood determinations.

100. Fiber Differentiation.—For convenience in studying fibers it is desirable to have a classification of fibers from a papermaker's standpoint, such as the following:

CLASSIFICATION OF PAPERMAKING FIBERS

A. Seed-hair fibers—fibers which grow on seeds: cotton.
B. Bast fibers—from the inner bark of trees, shrubs and other plants: flax (linen); hemp; jute; ramie; kodzu (paper mulberry); mitsumata; gampi.
C. Leaf fibers—from the leaf or leaf stalk: New Zealand flax; abaca (manila); sisal; aloe (American century plant); pineapple.
D. Hull fibers: cocoanut.
E. Stem fibers—from the main stem or trunk of the plant: wood fibers, coniferous; wood fibers, deciduous; straw; esparto; bagasse; cornstalk.

It should be pointed out that this is not a botanical classification, and any standard textbook on botany should be consulted if this information is wanted.

While the microscope yields valuable information, the methods of microscopy must be used with care and caution: the personal equation is often a large factor. Then, too, it is necessary to deal with materials that are often abnormal, in the sense that the 'ideal' material is seldom found. It is entirely possible that some characteristic fiber or cell may have been removed or lost. Beating may alter the fibers considerably. Caution should also be observed in interpretation of illumination effects. Further, it should be borne in mind that trials on known materials are a great help in identification.

The different kinds of fibers are identified by morphology, that is, by their characteristic form and structure, and by characteristic colors developed when they are stained. No attempt will be made here to go into the morphology of fibers, because of the extensive discussion and fiber illustrations required.

Reference should be made to the many excellent publications dealing with the subject. Such information should, however, be supplemented by the microscopist's examination of authentic samples of the different kinds of fibers.

IDENTIFICATION BY STAINS

101. Preparation of Sample.—A representative sample is obtained by taking a number of small pieces from various parts of the sheet. These are then boiled in a 0.5% to 1% caustic soda solution for a few minutes, the solution is poured off, and the sample is washed several times with clear, hot water. This operation may be performed in a test tube, small beaker, or dish; but since a test tube is very generally used for the further treatment of the sample, it will serve very well for the boiling operation. After washing the sample as just directed, roll the pieces between the thumb and finger, to form a small ball and to loosen the fibers; place this in a test tube that is about half full of water, add a drop or two of dilute acetic acid, and shake vigorously, to reduce all portions of the paper to pulp. A small portion of the sample is then removed from the test tube, placed on a microscope slide, and stained.

102. Removing Sample from Test Tube.—There are several methods of removing the sample from the test tube: (1) After it has been shaken, if the mixture is not too dilute, clots of fibers will be found adhering to the walls of the tube; and an entire clot, of about the right size, may be removed by means of a needle, to be used in preparing the slide. (2) Shake the test tube, and then incline it at an angle; insert the needle, and remove a small bundle of fibers from the pulp. This method works well when all the fibers are long; but, if the paper consists of a mixture of long and short fibers, there is a tendency to secure too large a proportion of the long fibers. (3) Make the pulp in the test tube more dilute, and remove the sample with a dropper; the dropper should be about 10 in. long and $\frac{7}{32}$ in. in diameter, with rounded walls at one end and a rubber bulb at the other. Shake the test tube, and quickly insert the dropper to a depth of 2 in.; expel two bubbles of air, and allow the pulp to replace it. Remove the dropper, and deposit the fiber in two drops on each of two slides. Evaporate the water in an air bath before staining.

This method is better than the second method, if very short fibers are present.

103. Removing the Water.—The water must be removed from the pulp sample before staining the fibers. This may be done by evaporation, or by using either absorbent paper (filter paper) or blotting paper that is free from fuzz. Pressing the fibers onto the slide with this paper removes the water, and leaves the fibers adhering to the glass.

STAINS

104. Herzberg's Stain.—The stain that is most widely known and used is Herzberg's stain; it consists of two solutions, and is best made as follows:

Solution A: To 50 grams of dry zinc chloride (fused sticks) $ZnCl_2$, in a small bottle, add 25 c.c. of distilled water, using a pipette for adding the water; place stopper in bottle, and shake. This should give about 40 c.c. of solution. Take specific gravity of the solution at 28°C., using a specific-gravity hydrometer or one graduated for both Baumé degrees and specific gravity. If the specific gravity is greater than 1.8, reduce it to 1.8 by adding water, and then pour into a tall cylinder.

Solution B: Take 12.5 c.c. of distilled water; use a part of this to wash the thermometer and hydrometer and to rinse the original container of the zinc chloride solution, and add to solution A. In what remains of the 12.5 c.c. of distilled water, dissolve 5.25 grams of potassium iodide and 0.25 grams of iodine; add this to solution A, stir well, and place in the dark. After standing over night, transfer the clear portion with a pipette into a black bottle, leaving a little of the solution above the sediment. To the clear solution, add a leaf of crystal iodine.

When this stain is used for analyses where color differences are important, it will be found satisfactory for at least 2 weeks, after which time, a new preparation should be made.

105. Applying the Stain.—When using Herzberg's stain, apply one drop to the fibers on the slide, tease the fibers apart with needles so they will be uniformly distributed, place over them a cover glass or thin slide, and the preparation is then ready for the microscope.

The following are the colors given by this stain:

Yellow or lemon yellow	Groundwood, jute, flax tow, uncooked manila hemp, and nearly all fibers containing large amounts of lignocellulose.
Blue or navy blue	Thoroughly cooked and bleached soda and sulphite wood pulps, cooked and bleached straw pulp and esparto.
Wine red	Cotton and linen rags, thoroughly cooked and bleached manila hemp, and certain Japanese fibers.

The stain should be tested with a mixture known to contain about equal parts of bleached soda, bleached sulphite, and rag fibers, to make sure that the colors given are correct. If the stain is satisfactory, the soda pulp should stain a dark blue color, while the sulphite, because of its thinner walls, will stain a light blue; the rag fibers will be stained a red or wine red. If the blue is not clear but tends toward the violet, too much iodine is present, and more water or zinc chloride should be added. Zinc chloride produces the blue color, iodine produces the red and yellow colors, and water serves to weaken the color that predominates. If all grades of paper are to be tested, it is well to keep several of these stains on hand, which have been so adjusted that the one best suited to a particular fiber may always be available. A stain that is suited to groundwood and unbleached sulphite will seldom give correct colors on rag and bleached soda and sulphite pulps; hence, it is necessary to adjust the stain to suit a particular fiber.

106. Sutermeister's Stain.—This stain is made up in two separate solutions, as follows:

Solution A: 1.3 grams of iodine and 1.8 grams of potassium iodide in 100 c.c. of distilled water.

Solution B: A clear calcium chloride solution containing 56.3 grams of calcium chloride $CaCl_2$ in 100 c.c. of solution. (That is, water is added to the calcium chloride until 100 c.c of solution is obtained.)

The colors given by this stain are practically the same as those given by the Herzberg stain and are as follows:

Red or brownish red: Cotton, linen, hemp, ramie.

Dark blue	Bleached soda pulps from deciduous woods.
Bluish or reddish violet	Bleached sulphite fibers and the thoroughly cooked part of unbleached sulphite.
Greenish	Jute, manila, and the highly lignified fibers in unbleached sulphite.

Yellow: Groundwood.

107. Applying the Stain.—In using this stain, apply a drop of solution A to the moist fibers on the slide. After a minute or so, remove the stain by absorbing the liquid with the edge of a piece of blotting or filter paper, and then press the paper down on the fiber; remove the paper, and immediately add a drop of solution B. Pull the fibers apart and distribute them evenly, by means of needles, and drop on a cover glass or thin microscope slide. If the solution is pressed out between the slides, remove the excess by means of a moist blotter or a damp cloth.

This stain must be protected from dust and evaporation, but it is unaffected by light. It is good until used up, and does not need frequent renewals, as does the Herzberg stain. Like the Herzberg, it should be tried out on known mixtures of fibers, and the strength of each solution should be adjusted until satisfactory colors are shown.

108. Lofton-Merritt Stain.—The Lofton-Merritt stain was devised to distinguish between unbleached sulphate and sulphite pulps. It consists of a mixture of 1 part of a 2% aqueous solution of malachite green and 2 parts of a 1% aqueous solution of basic fuchsine or magenta; the two solutions should be kept separate, in well-stoppered bottles, and should be mixed only when wanted. Since the dyes mentioned vary considerably in quality, it is possible that the proportions of the two solutions as here recommended may not give the best results; hence, after the separate solutions are made up, it will be necessary to try them on mixtures known to contain both sulphate and sulphite fiber, and also on authentic samples of each separately, altering the proportions of the solutions until the fibers are stained the proper colors. All the sulphite fibers should be purple or pink, and all the sulphate fibers should be blue or blue green. In

testing the solutions, if any of the sulphate fibers are purple, too much fuchsine solution is present; while if any sulphite fibers are green, this is an indication too much malachite green has been used.

109. Applying the Stain.—After the sample has been prepared in the usual manner and transferred to the slide, two or three drops of the compound stain are added and allowed to stand 2 minutes, during which time the fibers are teased apart and moved about in the stain; this insures a thorough contact with the stain, and it gives all the fibers an equal opportunity to be stained. The stain is then removed with absorbent paper, and the fibers are treated with three or four drops of very dilute hydrochloric acid (1 c.c. of concentrated acid in 1 liter of distilled water). The fibers are moved around rapidly in the acid for from 10 to 30 seconds, and the acid is then removed with blotting paper. The fibers are then washed with one or two changes of water and are finally mounted in water for observation. The contrast in color is sufficiently distinct to allow a very fair estimate of the proportions of the two fibers present. This stain will not work with *bleached* sulphate and sulphite fibers.

110. Alexander's Stain.—Alexander's stain is of value for differentiating between deciduous and coniferous woods; it consists of three solutions, as follows:

Solution A: 0.2 gram of Congo red in 300 c.c. of distilled water.
Solution B: 100 grams of calcium nitrate $Ca(NO_3)_2 \cdot 4H_2O$ in 50 c.c. of distilled water.
Solution C: The regular Herzberg stain.

The sample to be tested is stained on the slide with 2 drops of solution A; after 1 minute, the excess is removed with a blotter, and the fibers are allowed to dry. Next, 3 drops of solution B is added and allowed to remain 1 minute; then 1 drop of solution C, the Herzberg stain, is added, the whole is quickly and thoroughly mixed, and a cover glass is put over it. The coniferous fibers should be an evenly stained pink, and the deciduous fibers dark blue. The vessels (broad cells) in hardwood deciduous pulp are hardest to stain; and if these give a color closely resembling that of the deciduous fiber, the stain is working satisfactorily. The slide may be examined immediately after making up; but

if it be allowed to stand 3 or 4 minutes, slightly stronger colors are developed. The intensity of the colors may be changed by varying the concentrations of the Congo red and the Herzberg stain.

111. Kantrowitz-Simmons Stain (Modified Bright Stain).—This stain is used to distinguish between bleached and unbleached pulps; in general, it gives a distinction between pure cellulose fibers and those which contain lignin. Rag fiber, bleached sulphite and soda pulps, or any thoroughly bleached materials are stained red; but unbleached sulphite, groundwood, jute, or any lignified materials, are stained blue. This stain consists of three solutions, as follows:

Solution A: Ferric chloride solution made up of 2.7 grams of $FeCl_3 \cdot 6H_2O$ for each 100 c.c. of distilled water.

Solution B: Potassium ferricyanide solution made up of 3.29 grams of $K_3Fe(CN)_6$ for each 100 c.c. of distilled water.

Solution C: 0.5 gram of benzopurpurine 4B crude in 100 c.c. of 50% alcohol (dissolved hot).

Mix equal parts of A and B, put a few drops on the slide, let stand for 1 minute, blot off; rinse in distilled water, blot, and stain with C. Let stand for 2 minutes, blot, rinse, and mount.

112. Graff's Stains.—Graff's stains are modifications of the iodine-zinc chloride type of reagents, which are widely used. Other chloride compounds are substituted for the zinc chloride in varying proportions. The *C stain* is applicable to the greatest variety of fibers, the others of Graff's group being limited to certain specific uses. They will all distinguish bleached chemical wood from unbleached chemical wood. The C stain has also been used to differentiate between certain types of bleached sulphate and bleached sulphite pulps. Great familiarity with the stain and its reactions, as achieved by experience, will doubtless render the individual observer more versatile in using it for various other fiber determinations. The C stain is a good general stain, similar in its reactions to Herzberg's and to Sutermeister's stains, which are both iodine-chloride compounds. The stain is prepared as follows:

A. STANDARD IODINE SOLUTION:

To 50 c.c. of distilled water, add 0.90 gram of dry potassium iodide, and 0.65 gram of dry iodine.

NOTE.—Intermix the dry potassium iodide and the dry iodine by crushing them together in a beaker; then add the distilled water, a drop at a time, crushing and mixing until the iodine is completely dissolved in the saturated iodide; then add the rest of the water.

B. ALUMINUM CHLORIDE SOLUTION:

This solution of 1.15 specific gravity at 28°C. is made by adding about 40 grams of aluminum chloride ($AlCl_3 \cdot 6H_2O$) to 100 c.c. of distilled water.

C. CALCIUM CHLORIDE SOLUTION:

This solution of 1.36 specific gravity at 28°C. is made by adding about 100 grams c.p. calcium chloride to 150 c.c. of distilled water.

D. ZINC CHLORIDE SOLUTION:

This solution of 1.80 specific gravity at 28°C. is made by adding about 100 c.c. of distilled water to 200 grams of c.p. zinc chloride (fused sticks in sealed glass containers).

The stain is then prepared as follows: To 20 c.c. of solution B, 10 c.c. of solution C, and 10 c.c. of solution D, add, after first having mixed solutions B, D, and C thoroughly, 12.5 c.c. of solution *A*. Mix well, pour into a tall, narrow vessel, and place in the dark. After 12 to 36 hours, when the precipitate has settled, pipette off the clear portion into a dark glass-stoppered dropping bottle, add a leaf of crystal iodine and keep in the dark when not in use.

NOTE.—All the standard solutions must be at their exact specific gravities, and must be measured with pipettes graduated to 0.1 c.c., or closer.

113. Other Stains.—In addition to the stains used for the determination of fiber composition as given in the official method, the following stains are used to detect the presence of groundwood fiber, being applied directly to the paper under examination:

(1) PHLOROGLUCINOL.—Dissolve 5 grams of phloroglucinol in a mixture of 125 c.c. of distilled water and 125 c.c. of concentrated hydrochloric acid. The solution should be kept in the dark as much as possible, as it is prone to lose its staining property on exposure to light. This solution produces a *magenta* or *wine-red* color on mechanical pulp. The color may be easily noted by applying some of the stain to a piece of newsprint paper, which contains approximately 80% of mechanical pulp, and will develop a *deep magenta color.* The depth of color is an indication of the amount of mechanical pulp present. A very light shade of color, however, does not necessarily prove the presence of

mechanical pulp, as partly cooked jute, partly cooked unbleached sulphite pulp, and some other fibers are also slightly colored.

An alternative formula is as follows:

Phloroglucinol	2 grams
Alcohol (95%)	100 c.c.
Concentrated HCl	50 c.c.

(2) ANILINE SULPHATE.—Dissolve 5 grams of aniline sulphate in 50 c.c. of distilled water, and acidulate with one drop of concentrated sulphuric acid. This stain produces a *yellow* color on papers containing a large percentage of mechanical pulp. This stain is not quite so sensitive to mechanical pulp as phloroglucinol, but it is easier to obtain and prepare.

(3) PARANITRANILINE.—Saturated solution in concentrated hydrochloric acid. This stain produces an *orange-yellow* color in the presence of mechanical pulp and other lignified fibers.

114. Quantitative Analysis of Fiber Mixtures.—The determination of the relative amounts of different kinds of fibers present in paper requires extensive experience in such work; therefore, the details are not given here. Two methods are used, the count and the estimation methods. In the former, which is the *standard method*, the number of each kind of fiber present in a given field is counted. An eyepiece equipped with a suitable reference point, such as a pointer or a cross-hair disk, is used. The slide is moved across the field of vision, and each fiber is counted as it passes the reference point. In the *estimation method*, the relative proportion of the different kinds of fiber present is estimated by simply recording the mental impression of the appearance of a field as a whole. This method requires much more experience than the count method, and frequent reference to known mixtures of fibers. The proportion of the various fibers found is reported in terms of percentages of the total fiber composition. The average error is about 5 per cent, and it is customary to report results to the nearest multiple of 5, that is 37% and 43% would be reported as 35% and 45%, respectively.

CHEMICAL TESTS

NOTE.—To make the subject of *Paper Testing* complete, it is necessary to include *chemical tests* as well as physical and microscopical tests. Those students who have not had experience in qualitative and quantitative

(chemical) analysis will probably find it somewhat difficult to understand some of the following directions and explanations, and no questions will be asked that such students cannot readily answer. Nevertheless, they are advised to read this part of the subject, and they will find much in the text of direct value to them; it will serve to supplement to some extent the information gleaned from the study of the Section on *Elements of Chemistry*, Vol. II. The details of all of the more common qualitative tests are given, but only the simpler quantitative tests are given in detail.

MOISTURE AND ASH

DETERMINATION OF MOISTURE

115. Amount of Moisture in Paper.—The amount of moisture in paper is determined in order to permit calculation of the other paper components on an oven-dry basis, to assist in the control of moisture content, and to find whether the paper complies with a moisture specification. In many uses of paper, particularly in printing and converting processes, the moisture content is very important, and paper-conditioning systems for its control are widely used. Since paper having a moisture content not in equilibrium with that of the surrounding atmosphere loses or gains moisture with great rapidity, care must be taken in testing deliveries, or in control work, to conduct the sampling as quickly as possible, and to place the sample immediately in an air-tight container, in which it is weighed. (The empty container may be weighed before or after the test.) Because different parts of the paper under test may vary considerably, it is desirable in such testing to use a large sample, 50 grams or so. For testing for calculation of amount of other components on oven-dry basis, the specimens for moisture determination should be exposed to the surrounding atmosphere beside the other specimens to be tested until all are in moisture equilibrium with the atmosphere. A 2-gram sample is sufficient for this purpose.

116. Procedure.—After the specimen is weighed, the cover of the container is removed, and the paper is dried in the container, in an oven having adequate circulation of air, at 100° to 105°C. (212° to 221°F.) for 1 hour. The container is then closed in the oven, removed to a desiccator, and cooled in the desiccator to room temperature. The container and paper are weighed, and the entire process is repeated until the weight is constant. The

results, in per cent, of duplicate determinations of moisture must agree within 0.2%. The per cent of moisture so determined subtracted from 100 gives the per cent of oven-dry paper.

In reporting this test, the amount of moisture is given as a per cent (*a*) of the original weight of the paper, and (*b*) of the oven-dry paper, to the nearest 0.1%.

DETERMINATION OF ASH

117. Degree of Accuracy.—The sample of paper to be tested for ash (a weight of 1 gram is here recommended) need not be weighed closer than 0.005 gram, *i.e.*, to the nearest 0.01 gram; because a 1% variation in the moisture content will introduce an error of 0.01 gram. If the maximum error in weighing 1 gram of the paper is 0.01 gram, then the maximum error in the weight of the ash will be 0.001 gram for every 10% of ash present. Therefore, since 0.001 gram = 0.1% of 1 gram, in a paper containing 10% ash, the results of the determination should be reported to the nearest *tenth* of 1%. If special accuracy is required, the paper may be weighed in the bone-dry condition; then, with the error due to moisture eliminated, it is possible to weigh the paper to ± 0.0005 gram, *i.e.*, to the nearest 0.001 gram, and the error will be 0.0001 gram for each 10% of ash; the results may then be reported to the nearest *hundredth* of 1%. The error is then one-tenth as great as before.

118. Quantitative Determination.—Burn in a silica or nickel crucible 1 gram of the sample of paper to be tested. A Meker burner is very convenient for this purpose, as some heavily loaded papers require considerable time and heat to burn the last traces of carbon. An electric muffle furnace is also recommended. Ordinarily, a white paper will give a white ash; but if mineral pigments have been used, the ash is likely to be colored. In any case, the ash should be free from specks of unburned carbon.

During the burning, care must be taken that a portion of the ash is not lost by air currents. The ash is often light and fluffy, and the strong currents of air from the burners may blow away a portion of it. For this reason, and to avoid loss of mineral components that may be volatilized, it is preferable to ignite at a low temperature until most of the carbon is burned off. While cooling, the crucible may be kept in a desiccator; but this is not

necessary, since the ash may be poured into a counterpoised aluminum[1] pan on a chemical balance as soon as the crucible is cool enough to avoid the danger of loss from convection currents. The ash will cool almost instantly, and it may be weighed at once. This saves the time required for the crucible to cool, and it also avoids the necessity of weighing the crucible. The ash as finally obtained includes all the non-combustible matter in the paper; it is called the *total ash*.

The ash may be derived from at least five sources: (*a*) the ash of the pulp from which the paper was made; (*b*) the ash from the various loading or filling materials added; (*c*) the ash from any surface coating or sizing; (*d*) the ash from mineral coloring materials or pigments; (*e*) the ash derived from alum used, though the amount traceable to this cause is very small and may be neglected. The complete quantitative analysis of an ash is not only a time-consuming process but it is also a complicated one; however, it is possible to obtain some idea of the composition of the ash by a few comparatively simple tests.

Once the paper is burned, it is impossible to determine what portion of the ash is derived from the coating and what portion from the filler. Therefore, if anything more than the total ash content be desired, the coating must be stripped from the 1-gram weight of paper before burning it. In the case of coated papers where casein has been used as the adhesive, this can be done as described in Art. **120.** The insoluble material may be filtered off, dried, and weighed. The filtrate may be evaporated to dryness, and the residue weighed. This latter will include the casein (or soluble caseinates, if such be present) and also any soluble material present. The ash obtained from burning the paper after the coating has been removed is called the *ash of the paper*. Then, evidently,

Total ash − ash of the paper = ash of coating
coating − ash of coating = combustible matter in coating

119. Amount of Ash in Paper.—It is quite possible for a paper to have 2% of ash without being loaded, *i.e.*, without having fillers added; this might be due to the ash in the pulp as well as to

[1] Aluminum is recommended, because it is less easily broken, and is also lighter, than glass.

the ash derived from water, color, alum, and sizing materials. Where the ash content is over 5%, the paper is certainly loaded.

120. Amount of Coating.—Mineral coating is best removed from paper by use of an aqueous solution of 1.5 grams of a suitable enzyme[1] and 25 c.c. of 0.1 N caustic soda per liter. About 25 square inches of paper is weighed, soaked in the solution for about an hour at 50°C., then placed on a glass plate, and the coating brushed off with a camel's-hair brush. After thoroughly washing the paper, it is dried and again weighed. The loss in weight is the amount of coating.

121. Determination of Mineral Loading or Coating.—In the case of mineral materials that are not changed in weight appreciably on burning the paper, such as clay and titanium dioxide, the weight of the ash may be taken as the weight of the filler present. The amount of most of the other fillers used must be calculated after analysis of the ash. Following is a table giving substances which may be found by analysis, and the filling or coating mineral materials indicated by them:

Substance	Mineral Material
Calcium sulphate	Crown filler, satin white, gypsum
Calcium carbonate	Chalk, whiting
Barium sulphate	Blanc fixe, barytes
Magnesium silicate	Talc, asbestine, agalite
Aluminum silicate	Clay
Barium carbonate	Barium carbonate
Titanium	Titanium pigment
Zinc	Zinc pigment
Calcium sulphite	Calcium sulphite

Considerable experience is required to interpret an ash analysis. The presence of calcium sulphate, for example, may not be caused by the minerals above listed, but to the use of a complex filler containing it, such as lithopone or titanox. A quantitative analysis is often necessary before an interpretation is possible.

Following are qualitative testing procedures by means of which the probable presence of the substance listed can be determined.

122. Tests for components which volatilize on burning the paper must be made on the paper itself. Carbonates are indi-

[1] Trypsin can be used for this purpose, but some of the mixtures of enzymes used commercially for desizing cotton and degumming silk have been found to be more rapid in action, less expensive, and more stable.

cated by foam when dilute hydrochloric acid is dropped on the paper. Zinc sulphide is indicated by odor of hydrogen sulphide, and calcium sulphite by odor of sulphur dioxide, when the paper is treated with boiling dilute hydrochloric acid. Procedure for qualitative analysis of the paper ash follows.

123. Qualitative Analysis of Paper Ash.—Burn sufficient paper to obtain at least 0.2 gram of ash. (An ash that is yellow when hot and white when cold probably contains zinc oxide.) Transfer the ash to a small beaker and warm in a small quantity of dilute HCl. If there is an insoluble residue, decant the acid solution through a filter paper, and repeat the operation twice, finally transferring the residue to the filter paper and washing it thoroughly.

If the acid solution smells of hydrogen sulphide H_2S, boil until the odor has disappeared. Add an excess of ammonium hydrate NH_4OH to a portion of the acid solution. A white gelatinous precipitate insoluble in excess of NH_4OH, shows the presence of *aluminum.* (A precipitate that redissolves is probably due to zinc.) Filter off any precipitate formed. To the filtrate, if zinc is suspected, add an excess of H_2S, and boil. A white precipitate indicates the presence of *zinc.* Filter if a precipitate occurs, and to the filtrate add a solution of ammonium oxalate. A white granular precipitate indicates *calcium.*

If a precipitate forms, filter it off; concentrate the filtrate by boiling, and add a solution of ammonium acid orthophosphate $(NH_4)_2HPO_4$, followed by NH_4OH. A crystalline precipitate indicates *magnesium.*

To another portion of the acid solution add a few drops of barium chloride $BaCl_2$ solution, and warm. A fine white precipitate will form if a *sulphate* compound is present.

Dry any residue from the acid treatment of the ash, burn off the filter paper in a platinum crucible, and add to the contents of the crucible a fusion mixture consisting of equal parts of sodium and potassium carbonates. Fuse to a clear mass, cool, transfer the fusion to a beaker, and heat gently with water. When the mass is thoroughly disintegrated, filter, and wash any residue thoroughly with hot water. To the filtrate add an excess of HCl, evaporate to dryness, and treat the residue with warm dilute HCl. A white, transparent, flaky residue shows the

presence of *silica*, from a silicate mineral. Filter off any such residue; and to half the filtrate add a solution of $BaCl_2$, when a white precipitate will form if an insoluble sulphate, such as *barium sulphate* $BaSO_4$, was present in the paper. To the other half of the filtrate add an excess of NH_4OH and boil. A white gelatinous precipitate indicates *aluminum oxide* Al_2O_3.

Dissolve the water-insoluble portion of the fusion with a considerable excess of dilute HCl, add an excess of NH_4OH, and boil. A white gelatinous precipitate shows the presence of aluminum. Filter off any such precipitate and add ammonium carbonate $(NH_4)_2CO_3$ to the filtrate. A white precipitate occurs if *barium* is present. Filter, add an excess of ammonium phosphate, cool, and stir thoroughly. A white crystalline precipitate indicates *magnesium.*

To test for titanium, place about 0.5 gram of the ash in a 250-c.c. beaker, add 20 c.c. of concentrated H_2SO_4 and 10 grams of ammonium sulphate $(NH_4)_2SO_4$, and boil for at least 5 minutes. An insoluble residue indicates *silica* SiO_2 or siliceous matter. Cool the solution, dilute to 100 c.c. with water, heat to boiling, let settle, and filter through double Whatman No. 42 paper. Test the filtrate with hydrogen peroxide H_2O_2. A clear yellow or orange color indicates the presence of *titanium.*

A considerable amount of calcium and sulphate in the ash soluble in HCl indicates the presence of *calcium sulphate* (crown filler) $CaSO_4 \cdot 2H_2O$ or, in coated paper, satin white. The presence of barium and sulphate in the acid-insoluble portion of the ash indicates *barium sulphate* $BaSO_4$ (blanc fixe or barytes). An alkaline ash containing calcium soluble in HCl, but with no sulphate present, indicates the presence of *calcium carbonate* $CaCO_3$ (whiting or chalk). The presence of barium in ash that is soluble in HCl, with effervescence, indicates *barium carbonate* $BaCO_3$. Considerable amounts of silica and aluminum indicate *aluminum silicate,* added as china clay. Considerable amounts of silica and magnesium indicate *magnesium silicate,* derived from talc or asbestine. A microscopical examination of the ash assists in determining the variety of siliceous minerals present. Titanium may be present in several forms, commonly as TiO_2 or TiO_2–$BaSO_4$. Zinc pigments commonly used are ZnS and ZnS–$BaSO_4$.

OTHER CHEMICAL TESTS

DETERMINATION OF PARAFFIN

124. Quantitative Test.—There are several paraffin solvents that may be used for this determination, among which are gasoline and carbon tetrachloride. Gasoline is easily obtained and is comparatively cheap; however, it has the serious disadvantage of being very inflammable. Carbon tetrachloride CCl_4 is not combustible, but it cannot be kept in 'tin' cans, because of its action on iron. Both gasoline and carbon tetrachloride have been found satisfactory for this test.

Enough of the paper must be taken to obtain a weighable amount of paraffin; 1 or 2 grams of paper is usually sufficient. Place the paper in a Soxhlet extractor or in an ordinary Erlenmeyer flask, fitted with a reflux condenser, cover with gasoline or carbon tetrachloride, and extract until all the paraffin is dissolved. If the Erlenmeyer flask be used, it will probably be necessary to make a second extraction with a fresh amount of the solvent. The solution may then be evaporated to dryness, and the paraffin weighed.

If the paraffin shows a tendency to 'creep' over the edge of the dish (flask), it may be easier to weigh the paper before and after the extraction, and consider the difference in weight as *paraffin.* The trouble may be prevented by keeping the upper part of the dish, the part above the level of the solution, warmer than that below it. It also is not likely to happen if petrolic ether of low boiling point is used as the solvent, since the vapors will not re-condense on the sides of the container.

125. Qualitative Test.—The following qualitative test for paraffin, known as the *Dunlop test,* may be of value in determining the presence of paraffin in the presence of rosin. It consists in boiling the sample with acetic anhydride, filtering hot, and observing the behavior of the solution on cooling. If paraffin be present, the anhydride becomes turbid, and the paraffin separates out on the top. Less than 1% of paraffin may be detected in this manner. (Allen's "Commercial Organic Analysis.")

ROSIN, GLUE, CASEIN, AND STARCH

126. Quantitative Test for Rosin.—Cut 5 grams of paper into strips that are approximately ½ inch wide, and fold them into numerous small, crosswise folds. Place the folded strips in a Soxhlet extractor, and fill with acidulated alcohol. The latter is made by adding 900 c.c. of 95% alcohol to 95 c.c. of distilled water and 5 c.c. of glacial acetic acid. Place the Soxhlet flask in the boiling water of a steam bath, and extract by siphoning at least 12 times, until the solvent comes over colorless. Wash the alcoholic extract, which may contain foreign material, into a beaker with hot water, and evaporate to a volume of a few cubic centimeters on a steam bath. Cool; take up in about 25 c.c. of ether, and transfer to a 300-c.c. separatory funnel that contains about 150 c.c. of distilled water, to which has been added a small quantity of sodium chloride to prevent emulsification; shake enough to mix well, but not violently or long, and allow the contents to separate, the water being at the bottom of the funnel. Draw off the water into a second separatory funnel, and repeat the treatment with 25 c.c. of ether, to take up any rosin that may have gone over with the water from the first funnel. Mix the two ether extracts, which contain the rosin and any other ether-soluble material, and wash twice, or until the ether layer is perfectly clear and the line between the ether and the water is sharp and distinct, with 100-c.c. portions of distilled water, to remove salts and foreign matter. Should glue, which is extracted from the paper by alcohol, interfere by emulsifying with the ether, it may be readily removed by adding a strong solution of sodium chloride to the combined ether extracts, shaking thoroughly, and drawing it off, repeating, if necessary, before washing with the distilled water. Transfer the washed ether extract to a weighed platinum dish, evaporate to dryness, and dry in a water oven at 98° to 100°C. for exactly 1 hour; then cool and weigh. This length of time is sufficient to insure complete drying: prolonged heating causes a loss of rosin. The weight thus obtained is, of course, the weight of the rosin in the sample.

Not less than two determinations should be made, and the average of the results is computed. The per cent of rosin obtained in duplicate determinations must agree within 0.2%.

Some objections have been raised as to certain details of the foregoing method. It has been claimed that the sodium chloride is sufficiently soluble in the ether to produce high results. Some analysts prefer to carry the evaporation of the alcohol extract to complete dryness, and then take up in ether and in water. The residue as obtained is only partially soluble in ether; but, in case the entire amount should not be secured, after as much as possible has been dissolved in the ether, the remainder of the residue is taken up in water. The ether and water are then separated in a separatory funnel in the usual manner. There appears to be no reason why a glass or porcelain dish should not be used instead of a platinum dish. If a platinum dish is used, the rosin, after weighing, may be burned off to see if any soluble mineral matter, *i.e.*, salt, is present. The number of extractions required depends on the character of the paper used. In some individual cases, it was found that a single extraction took out practically all the rosin; this extraction was done on a hot plate, and the alcohol was in contact with the paper for about ½ hour. It is not known to what extent this time could be shortened, or in what per cent of cases a single extraction would be sufficiently accurate.

127. Underwriter's Extractor.—For extracting rosin, the apparatus shown in Fig. 16, called the underwriter's extractor, will do the work of a Soxhlet extractor, and with greater convenience. It consists of an Erlenmeyer flask, into the top of which is inserted a worm, which is attached to a plate that covers the top of the flask. The two ends of the worm are connected to rubber tubing, as shown, so that cooling water may be circulated through the worm. A siphon cup containing the folded strips of paper is suspended in the flask directly under the worm. The acidulated alcohol solution in the bottom of the flask does not touch the perforated disk; and, on being heated, the vapors are condensed by the worm, the drops fall on the paper in the dish, and, as they fall into the bottom of the flask, they carry the rosin with them. The principle is essentially the same as the Soxhlet for extracting the rosin. This apparatus can be set up very quickly; it takes less solvent, keeps the condensed solvent surrounded by hot vapors, occupies less space, and is less liable to breakage than the Soxhlet; the time of extraction

is also lessened, because of more frequent flushing of the siphon cup (dish) with the condensed solvent.

128. Qualitative Test for Rosin.—There is no single test of a simple nature that will demonstrate positively the presence or absence of rosin; and any opinion regarding it must be based on the indications of a number of different tests. If a little ether be dropped on a sheet of paper and allowed to evaporate, there will

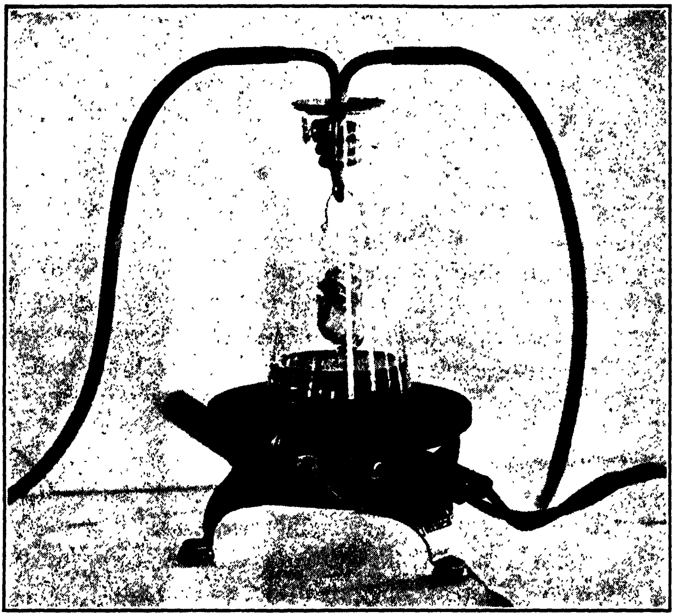


Fig. 16.

be formed, in the case of rosin-sized paper, a ring of rosin at the edge of the spot where the ether evaporated. This is not a very delicate test, since this ring will be formed on any paper that contains any ether-soluble material other than rosin.

A positive result obtained by both of the two following methods may be regarded as conclusive evidence of the presence of rosin in paper.

Lieberman-Storch Method.—Place in a clean, dry test tube 1 gram of paper cut in small pieces. Add 5 c.c. of chemically pure acetic anhydride, and boil down to about 1 c.c. (The fumes of the anhydride are very irritating, and they should be burned as

they leave the test tube.) Pour the liquid residue into a clean, dry porcelain crucible, and cool to room temperature, preferably lower. If any waxy particles separate, they should be filtered off through a *dry* paper. Add carefully, down the side of the crucible, one drop of concentrated sulphuric acid. A fugitive rose-violet coloration, formed when the acid meets the anhydride, indicates rosin.

RASAIL METHOD.—Place the paper on a glass or porcelain plate, and apply a drop of strong solution of sugar. After a few moments, remove excess sugar solution with filter paper. Add a drop of concentrated sulphuric acid to the sugar on the paper. A raspberry-red coloration indicates the presence of rosin.

A third test, recommended by Crolard,[1] is to tear into small fragments a portion of the paper to be tested for rosin and boil in a few cubic centimeters of carbon tetrachloride. Decant into a test tube 2 or 3 c.c. of the liquid, and add $\frac{1}{2}$ c.c. of acetic anhydride; then add a few drops of concentrated sulphuric acid, pouring very carefully down the sides of the test tube, so as to avoid mixing with the solution. If rosin is present, a beautiful violet-red color will develop at the line of contact of the two liquids; but, if the amount of rosin is small, only a rose-colored ring will be formed. In either case, the color is fugitive; it disappears fairly rapidly, and the whole liquid turns greenish.

129. Effect of Moisture in Paper.—In the article by Crolard just referred to, he points out, as follows, the importance of working with bone-dry paper, or else allowing for the moisture content, when making the quantitative test for rosin:

"The normal moisture content of paper is of the same order as that of rosin. Suppose there was 7% of rosin in a paper containing 5% of moisture; then 100 grams of bone-dry paper would contain $7 \div 95 \times 100 = 7.37$ grams of rosin; and if there were no correction made for the moisture content, there would be an error of $(7.37 - 7) \div 7 \times 100 = 5.3\%$ of the amount of rosin. This would be equivalent to an error of $5.3 \div 0.40 = 13.2\%$ for a rosin soap containing 40% of total rosin."

130. Quantitative Test for Glue and Casein.—There is no known method of determining the amounts of glue and casein

[1] Jacques Crolard, "The Analysis of Paper." Translated from *Le Moniteur de la Papeterie Francaise* by A. Papineau-Couture; *Pulp and Paper Magazine of Canada*, May 29, June 5 and 12, 1924.

when both are present in the same sample. But, since both the substances contain nitrogen, if only one be present, and the nitrogen content of the material as added to the paper be known, then, by means of the nitrogen determination of the sample, the content of glue or casein may be found. The determination of nitrogen is very technical; it should be performed only by an experienced chemist, and will not be given here. The method may be found in any good work on quantitative analysis (for example, Treadwell's "Analytical Chemistry," translated by Hall; also, Tappi Standard T-418-m.).[1]

131. Qualitative Test for Nitrogenous Matter (Glue or Casein).—A positive result obtained by the following method may be regarded as conclusive evidence of the presence of nitrogenous (proteinaceous) materials, such as glue and casein, in paper.

Boil 0.5 gram of paper for several minutes with 10 c.c. of a 1% solution of caustic soda. (Caustic soda is necessary, as the nitrogenous materials may have been made insoluble in water by hardening treatment with formaldehyde or other agents.) Filter off the aqueous extract, and, after cooling, add a suitable indicator, such as phenolphthalein, then exactly neutralize with hydrochloric acid. Prepare Schmidt's reagent by dissolving 3 grams of chemically pure ammonium molybdate in 250 c.c. of distilled water, and adding 25 c.c. of chemically pure nitric acid of 1.2 specific gravity. (This reagent is not permanent, and should be made fresh at frequent intervals.) Add 1 volume of the reagent to 2 volumes of the aqueous extract. A white precipitate shows the presence of nitrogenous materials derived from proteins.

This test is very delicate. If no precipitate or only a slight precipitate is obtained, there can be no appreciable amount of proteinaceous materials present.

Glue is sometimes used as an adhesive in coating papers and, in rare instances, in beaters; the better grades, known as gelatines, are used in surface sizing. Casein is principally used as an adhesive in coated papers.

132. Qualitative Test for Casein.—Casein may be detected in paper by moistening the sample with Millon's reagent,[2] and

[1] Published by The Technical Association of Pulp and Paper Industry, New York.

[2] Prepared by dissolving mercury in an equal weight of cold, fuming nitric acid (sp. gr. 1.42), then applying moderate heat, and finally diluting with 2 volumes of water.

warming gently, either over a flame or over an open steam bath. If casein is present, a brick-red color will develop. In the case of coated paper in which much satin white is used, the alkali present determines the formation of a yellow color. In this case, proof of the presence of casein may be obtained by moistening the paper first with dilute nitric acid, to neutralize the alkali, and then applying Millon's reagent as before. Tested in this way, satin-white-coated paper containing casein will give the usual red color.

Casein may also be detected by boiling the paper with water and a few drops of ammonia, filtering, and adding to the filtrate (very gradually) dilute acetic acid. Casein will precipitate when the solution becomes very faintly acid, but it may re-dissolve on adding acid to a considerable excess. This test is also given, though usually less strongly, by rosin; hence, the precipitate should be tested with Millon's reagent to confirm the presence of casein. Casein is seldom used except in the coating; cases of its use in surface sizing or in the beaters are very rare.

133. Qualitative Test for Starch.—Make a dilute solution of iodine in potassium iodide by adding a small amount of water to a mixture of 3 or 4 crystals of iodine and 1 gram of potassium iodide KI, stirring until the iodine is completely dissolved, and then diluting the solution with pure water until a pale straw-yellow color is obtained. Place a drop of this solution on the paper being examined; a blue color indicates the probable presence of *starch*. If this blue coloration is obtained, confirm the test by boiling the paper with water and testing the cooled extract with the iodine solution; because cellulose in the presence of water gives rise to modifications called hydrocelluloses when subjected to certain mechanical processes. These hydrocelluloses are not soluble to any great extent in boiling water, but they give rise to a blue coloration when brought into direct contact with the iodine solution.

134. Colorimetric Test.—In the article by Crolard referred to in Art. **128,** he recommends the following colorimetric test:

"On placing a drop of dilute iodine solution on the paper, a blue color is formed in the presence of starch. By comparison of the color produced by a very dilute solution of iodine in potassium iodide on the sample and on a series of papers of known starch content, the amount of starch can be estimated to within 0.5%."

135. Quantitative Determination of Starch.—The starch is converted into a sugar, dextrose, by treatment with a boiling mixture of water and saliva. The dextrose precipitates copper quantitatively from Fehling's solution, which contains copper sulphate. The precipitated cuprous oxide is either weighed or dissolved, and the amount is determined by titration.

SULPHUR, CHLORINE, AND ACIDITY

136. Sulphur.—The amount of reducible sulphur compounds in paper used to wrap metal articles, particularly silverware, is of importance, because such sulphur compounds may tarnish metal. To determine the amount, the paper is placed in a flask with aluminum foil and dilute phosphoric acid, and in the neck of the flask is inserted filter paper moistened with lead acetate. On heating the mixture, hydrogen sulphide is evolved from the reducible sulphur compounds, and causes staining of the filter paper. The amount of sulphur is then found by comparing the depth of stain with that produced under like conditions by known amounts of a reducible sulphur compound. Paper that, when tested in this way, shows less than 0.0008 per cent sulphur can probably be assumed to be non-tarnishing, insofar as sulphur is concerned. However, if more than this is found, the paper will not necessarily cause tarnishing, and, in this case, an accelerated tarnishing test should be made by wrapping the polished metal in the paper after saturating the paper in water, and heating at 150° to 190°F. until the paper is dry.

137. Chlorine.—The determination of free chlorine in paper is carried out in a manner similar to the method used in testing half-stuff: namely, take from the beater a small mass of the stuff to be tested, press it with the hand, and test with a few drops of potassium iodide-starch solution; if free chlorine is present, the characteristic blue color will develop.

For the testing of finished paper, the determination is best carried out as follows: Cut the paper into small pieces, moisten with distilled water, and test with starch-iodide paper; this is best done on a glass plate. Or, instead of starch-iodide paper, mix a small piece of starch to a paste with cold water, and then mix the paste with a solution of potassium iodide.

138. Importance of Acidity.—Too much acid in paper is undesirable, as it may cause deterioration of the paper and of other materials in contact with the paper; it is practically all derived from the alum used in papermaking processes. Acidity is a very important mill-control test, because the amount of alum used must be carefully controlled to obtain the best results in the coloring and sizing operations, in paper formation, filler retention, and in other respects, without having the paper too acid.

139. Determination of Acidity.—Paper may be extracted by treatment with boiling water, and the extract titrated with tenth-normal caustic soda solution, using phenolphthalein as an indicator. It is now realized, however, with respect to all materials where acidity is important, that determination of hydrogen-ion concentration, commonly measured in terms of pH, is preferable, because it measures the *intensity* of the acidity, while titration measures only the amount of acid present (see *Sizing of Paper*, Vol. IV). For example, tenth-normal acetic and hydrochloric acids would give the same test values by titration; but the pH value, and therefore the intensity, of the hydrochloric acid solution would be 60 to 70 times that of the acetic acid.

NOTE.—The only constituent common to all acids is hydrogen, hence, the characteristic property of acids must be due to hydrogen. Any acid in solution in water tends to dissociate into electrically charged bodies, called *ions;* namely, the characteristic hydrogen ions and the other ions of which the acid is composed. Hydrochloric acid, for example, dissociates into hydrogen ions and chlorine ions; boric acid, into hydrogen ions and borate ions. The hydrogen-ion concentration, measured by the pH, of a solution is the total amount of ionized hydrogen per unit volume of the solution. Similarly, the characteristic properties of an alkali are attributed to the OH (hydroxyl) radical, and the activity of alkalis is due to the concentration of the OH ions. A neutral solution at 21°C. has a pH of 7; values below this indicate increasing acidity as the numbers grow less, and values above 7 indicate increasing alkalinity as the numbers grow larger.

The pH determinations are made on an aqueous extract of the paper. Two methods are used, colorimetric and electrometric. By the colorimetric method, a series of indicators having color changes covering a wide range of pH values are used with standard solutions of known pH values. The different indicators are added to test tubes containing portions of the extract, and the colors are compared with those of the standard solutions. The electrometric method requires rather elaborate electrical apparatus, but it gives more accurate results and takes less time.

140. Alpha Cellulose and Copper Number.—Tests for alpha cellulose content and copper number are made to find the degree

of purity of the paper fibers, relative to the probable stability of the paper. These tests are fully described in Vol. III. Alpha cellulose is that part which remains undissolved when fibers are treated with 17.5% solution of caustic soda under certain conditions involving amount of solution, time, and temperature. Some forms of cellulose reduce copper, in the form of cuprous oxide, from a solution of cupric hydrate, and the *copper number* is defined as the number of grams of metallic copper in the cuprous oxide that would be reduced from the cupric hydrate by 100 grams of paper fiber. High alpha cellulose and low copper number are indications of fiber stability.

MINERAL COLORING MATTER

141. Smalts.—Smalts (or smalt), cobalt blue, existing as it does in high-class papers, usually without admixture with loading materials, can be estimated with sufficient accuracy by incinerating the paper, weighing the ash, and making a correction for the small proportion of the latter due to the fiber; this proportion does not usually exceed 2%. The blue color of the ash is not affected by acids.

142. Ultramarines.—The ultramarines are of variable and even of doubtful composition; they are therefore best estimated by comparing the depth of color of the ash against that of standard mixtures of the pigment with known proportions of china clay. The color of the ash is destroyed by acids, and hydrogen sulphide may be noted.

143. Chrome Yellow, Orange, etc.—Chrome yellow, orange, etc., also of variable composition, may be determined, if necessary, by estimating the lead and chromium separately and calculating the results to the nearest indicated composition. The full analysis is seldom required; and it is only necessary to state here that the lead is precipitated and estimated as the sulphate, and the chromium as chromic oxide.

144. Prussian Blue.—Prussian blue may be determined approximately by estimating the iron, the process being to ignite the paper, fuse the ash with sodium carbonate, and then treat the fused product with hot water, filter, and boil the residue with dilute hydrochloric acid, to which is added a drop or two of nitric acid The solution is then again filtered, and the iron and

alumina precipitated with ammonia in the presence of a little ammonium chloride. The precipitate of iron and aluminum hydrates is washed, filtered off, and digested with an excess of caustic soda; then filtered again and carefully washed. The residue, which consists entirely of iron, is washed, dried, ignited, and weighed as the oxide. This process also serves for the estimation of all iron pigments, except the natural pigments, ochers, etc.

145. Bibliography.—Following is a list of books relating to paper testing. The list of separate articles is so extensive that it is not feasible to include it. The more important articles are listed with the various TAPPI testing methods, and a very complete list will be found in West's "Bibliography of Papermaking."

Allen: "Commercial Organic Analysis," Vol. I, pp. 465–480.
Bromley, H. A.: "Paper and Its Analysis," Vol. III, pp. 141–212.
Cross, C. F., and Bevan, E. J.: "A Text Book of Paper-Making," pp. 371–402.
Griffen, R. B., and Little, A. D.: "Chemistry of Paper Making," pp. 400–451.
Griffin, R. C.: "Technical Methods of Analysis," pp. 337–363.
Herzberg, Wilhelm: "Paper Prüfung" (Paper Testing).
Klemm, Paul: "Handbuch der Papierkunde" (Handbook of Paper Technology), pp. 248–327.
Maddox, H. A.: "Paper, Its History, Source, and Manufacture."
Sindall, R. W.: "Elementary Manual of Paper Technology," pp. 107–213.
Stillman, T. B.: "Engineering Chemistry," 5th ed., pp. 561–568.
Sutermeister, Edwin: "Chemistry of Pulp and Paper Making," 2d ed., pp. 463–511.
Witham, Sr., G. S.: "Modern Pulp and Paper Making," pp. 462–500.

PAPER TESTING

EXAMINATION QUESTIONS

1. (*a*) State reasons for making paper tests. (*b*) Why should records be kept of all tests?

2. How should samples for testing be taken?

3. What is meant by (*a*) machine direction? (*b*) cross direction? (*c*) wire side? (*d*) felt side? (*e*) State how you would distinguish the foregoing paper characteristics.

4. Suppose you were given a small sample of paper that measured $3\frac{1}{16}$ in. by $2\frac{1}{3}\frac{9}{2}$ in. when trimmed to an exact rectangle. If the sample weighed 0.39 g., (*a*) what would be the weight of standard ream of this paper? (*b*) What would be its substance number?

$$\text{Ans.}\begin{cases}(a)\ 53.87 \text{ lb.}\\(b)\ 20.15, \text{ say No. } 20.\end{cases}$$

5. Referring to the last question, (*a*) what would be the weight of the sheet in grams per square meter? (*b*) What would be the weight of a ream 24 × 36—480 if the weight of a sheet were specified as 72 g./m.^{2}?

$$\mathit{Ans.}\begin{cases}(a)\ 75.74 \text{ g./m.}^2\\(b)\ 42.46 \text{ lb.}\end{cases}$$

6. What is the length of the paper in a roll of newsprint, 24 × 36—500, 32 lb., if the width is $72\frac{5}{8}$ in. and it weighs 1280 lb. without the core? *Ans.* 19,828 ft.

7. The average of 10 tests of the tensile strength of a sample of paper, 25 × 40—500, 55 lb., was 5.91 kg. per 15 mm. of width; what was the breaking length of this sample? *Ans.* 5571 yd.

8. As applied to paper, (*a*) what is meant by bulk? (*b*) How does bulk differ from thickness? (*c*) How is bulk tested?

9. Mention some of the effects produced in paper by changes in the relative humidity of the surrounding atmosphere.

10. What is polarized light?

11. What is (*a*) chromatic aberration? (*b*) spherical aberration? (*c*) an aplanatic lens? (*d*) In a compound microscope,

which magnifies the most, the ocular or the objective? (*e*) Is the image seen through a compound microscope inverted or direct, and why?

12. What is a microtome, and for what purpose is it used?

13. Describe a method for testing (*a*) the absorbent power of blotting paper, and (*b*) of printing ink.

14. (*a*) Mention some of the tests that are best performed with a microscope. (*b*) Explain how you would detect coal particles and iron scale, and how you would separate them.

15. Why are stains used? Explain in detail.

16. (*a*) Why is paper tested for moisture content? (*b*) How is it determined?

17. How would you determine (*a*) the combustible matter in a sample of paper? (*b*) in the coating?

18. Describe a test for indicating the presence of rosin in paper.

19. (*a*) How would you detect the presence of starch in paper? (*b*) What chemical reaction indicates the presence of a carbonate in paper?

20. (*a*) Why is opacity an important property of paper? (*b*) How would you determine which one of several paper samples of practically the same color was the most opaque?

SECTION 6

PAPERMAKING DETAILS

INTRODUCTION

REMARK.—This Section has been prepared in response to requests received from students and others for a summary of the principal points to be observed in the manufacture of various grades of paper and boards. The information herein contained was largely obtained through the distribution of questionnaires, which were afterward reduced to textbook form, and then submitted to various authorities for criticisms and amendments. The editor gratefully acknowledges the assistance of W. G. MacNaughton, at that time secretary of the Technical Association of the Pulp and Paper Industry, in the preparation and distribution of the questionnaires, practically all of which were returned, many mills supplementing their answers with additional helpful information. The sincere thanks of the Textbook Committee are extended to all who have so cordially cooperated in this work, and particularly to R. S. Hatch, F. C. Clark, and A. O. Bragg for their assistance in converting the questionnaires to textbook form, and to Miss Helen Kieley and Randall Doughty for assistance in revising this Section.

The definitions are largely based on those in "Paper Definitions" (Lockwood Trade Journal Co., New York), modified to accord with statements made in the answers to the questionnaires. Manufacturing operations and terms are not described or defined, it being assumed that the reader is familiar with mill processes and terms. If in doubt, he can readily refer to previous Sections of this textbook, especially to those on beating, sizing, paper machines, and finishing; the indexes to the several volumes will be found very helpful in such cases.

Since a work of this character has apparently not been attempted heretofore, it is probable that many improvements can be made in it, and suggestions and working material to that end will be thoroughly appreciated.

1. Explanatory.—For convenience of reference, this Section has been divided into two parts, Part 1 being devoted to papers, and Part 2 to boards. In both parts, the items treated have been arranged alphabetically, to make them easy to locate; each item has been given an article number, for ease of cross reference. Some of the items are definitions only; but, in the majority of cases, in addition to the definition, information concerning the use of the paper or board, and details of its manufacture, are also given, the arrangement being as follows: (*a*) A definition of paper or board, its principal uses, and the qualities or characteristics it should have; (*b*) a statement of the fibrous materials generally used, and sometimes giving a specimen furnish; (*c*) a description of the treatment to be given to the papermaking material in the beater and Jordan, and the character of the stock (long, short, free, wet, etc.), kind and amount of sizing, loading, color; (*d*) a statement of the kind of papermaking machines used, the speed, consistency of stock, kind of finish given, whether shipped in rolls or sheets, and any special remarks considered appropriate.

The student is not required to *study* this Section, and no Examination Questions are appended; but it will be greatly to his advantage to read it through, and devote particular attention to those items in which he is directly interested: a great deal of valuable information is herein contained in a condensed form. Thus, take the item *Cigarette Tissue:* it is doubtful if the information given in Art. **18** regarding this paper is available in any other publication, particularly concerning the making and finishing; and this same statement will apply equally to many other items.

PART 1—PAPERS

2. Absorbent Paper.—A general term that applies to papers made to absorb water or special chemicals, for subsequent conversion into cellulose products. To secure absorbent quality, these papers must be soft, loosely felted, and bibulous, or relatively thick for their ream weight. They are unsized, and are referred to as 'waterleaf.' The following papers are included under this term: blotting, red and white stereo blotting, filter papers, towelings, base stock for making vulcanized hard-fiber nitrating tissue, vegetable parchment, acetate papers, bakelite, artificial leather, and impregnated papers.

MATERIALS: Soft rags and alpha fiber are used in the higher grades of blotting, filter, and base papers for chemical processes. Lower grades of blotting, toweling, etc., contain up to 100% wood fiber—hardwood sulphite and soda pulp. Sulphate pulp is used in brown towels, and some groundwood pulp may be used in the lower grades of toweling.

PREPARATION: In cooking rags for an absorbent paper—vulcanized hard-fiber paper, for example—good practice recognizes that small amounts of an alkali (about 4% to 8% soda ash), low cooking pressure (not over 30 lb.), and not over 8 hours' cooking, will give best results. These papers require a free stock, and the equipment is manipulated accordingly.

In making towel paper of 60% sulphite and 40% groundwood, some strength is required; therefore, the stock is well mixed in the beater and jordaned fairly hard. It is tinted with methylene blue, rhodamine, or other similar colors, and slightly sized, using 1% or less of rosin. No loading is used for filter paper or papers to be used for subsequent chemical treatment, but is present in cheap blottings.

MAKING AND FINISHING: If the blotting or filter paper be thin, a close formation is usually wanted; for thick papers, formation is not as important. The stock is prepared long or short, as required in each case. Fourdrinier machines are generally used, the speed ranging from 50 to 500 f.p.m. (ft. per min.) for papers from 240 to 40 lb. per 1000 sheets, 19 × 24, and 300 to 1000 f.p.m.

or higher for towel paper. A low steam pressure in the dryers should be used on all absorbent papers, since this helps their absorbency.

3. Anti-Tarnish Paper.—A general term applied to papers made of rags, alpha cellulose, sulphite, sulphate, or jute; they are used as wrappers to keep metal parts from rusting or tarnishing. The paper must be free from sulphur compounds, acid, or alkali. The term was originated for a lightweight sheet or tissue, made from rags and carefully bleached and washed; this grade was used to wrap silverware and steel tools, cutlery, and other polished steel hardware. Later, the term has been applied to wrapping paper made from bleached sulphite free from acid or sulphur compounds.

MATERIALS: Best grades are made of chemically refined or bleached sulphite; lower grades are little more than ordinary wrapping paper made of various wood pulps.

PREPARATION: Best grades are carefully washed, bleached, and washed again to remove bleach residues. They are beaten for strength and run over a Fourdrinier, with or without a Yankee dryer, depending on finish desired.

MAKING AND FINISHING: No special points on making, except to get uniform formation. The paper is usually sold in frames or cases for the higher grades, and in bundles for lower grades.

4. Asbestos Paper.—A term applied to a group of building papers, made wholly or principally of fibrous asbestos; used as a fire preventive and for heat-insulating purposes.

MATERIALS: Asbestos fiber from the mineral asbestos. It is either mixed with cement and molded into thick sheets, called asbestos lumber, or it is broken up in a crusher, then in a beater, and run over a cylinder machine into soft, spongy sheet form, which is sometimes used to wrap pipes to reduce radiation losses. (But this results in increasing radiation—because of the larger surface thus formed—as asbestos is a fair conductor of heat.)

PREPARATION: The mineral is first crushed (as in rock crushing); it is then beaten in a regular paper-mill beater and run over a cylinder machine, much like ordinary heavy mill wrapper.

FINISHING: Generally sold in rolls, suitably wrapped for shipment.

5. Bag Paper.—The chief requirement is that the paper shall be strong enough to carry the contents of the bag. The kinds of paper used are tissue, bogus manila, glassine, kraft, paraffin coated, rope, jute, vegetable parchment, wood manila, sulphite wrapping, etc.; in fact, almost any paper can be used, if strong enough.

MATERIALS: For this paper, the fiber furnish is varied to suit the product desired, though kraft pulp is used more than any other raw material.

MARKING AND FINISHING: Fourdrinier machines are best suited to bag papers, because better formation and greater speed and production can be secured. The modern machines on lighter weights operate up to 800 or 900 f.p.m. The calendering is usually light; the paper is slit, and is rewound into rolls for automatic bagmaking machines.

6. Bible Paper.—A lightweight, opaque, printing paper, in which a large number of sheets per inch of bulk, strength, and opacity are the chief characteristics. This paper was first developed in England under the name of India Bible or India Oxford Bible; it was first used for printing Bibles, so as to have the complete Bible form a book of ordinary thickness. The best India Oxford bible paper weighs approximately 16 lb. for 25 × 38—500, and 2000 pages will bulk about 1 inch. Bible papers made in the United States run from 20 to 30 lb. for 25 × 38—500.

MATERIALS: New cotton and linen rags and small amounts of manila hemp are used in the best grades, which are of the lightest weights. The lower grades, which are of heavier weights and run from 26 to 30 lb. for 25 × 38—500, may contain sulphite, or even small amounts of soda pulp; may also be made almost entirely of wood pulp in low grades that are really lightweight E.F. book. All bible papers are heavily loaded with a special loading of kaolin and chalk, which may run as high as 30% ash in the best papers. Very little rosin size and alum is used, especially in the best grades.

PREPARATION: Great care must be exercised in the preparation of rags for the highest grade bible papers. They are cooked at low pressure with weak alkali, and are bleached with the least possible amount of chlorine. New white rags may best be handled without cooking or bleaching. The beating operation

is most important, and is best carried out in small beaters of 250 to 500 lb. capacity. The stock is cut short and then thoroughly brushed out: the beating operation may take from 15 to 25 hr.

MAKING AND FINISHING: The paper-machine screens and the Fourdrinier paper machine are both specially designed to make a high-grade bible paper. The speed is 100 to 150 f.p.m., the wire is of 100 mesh or finer, and there are special 'pickup' felts to carry the sheet from couch roll to first press and from last press to first dryer. This paper is very lightly calendered, cut into sheets of proper size, and cased with ream markers for shipment.

7. Bogus Wrapping.—A coarse, cheap wrapping paper, usually gray in color and having little strength; made from old mixed papers, pulp-mill screenings, rag-room dust, and other waste material; also known as rag wrapping, gray rag, or gray wrap; used for wrapping when covering, not strength, is desired.

MATERIALS: Cheapest grades of old mixed papers, rag dust from textile mills or paper-mill rag room, and pulp-mill screenings. The sheet should be well sized with rosin size and alum.

PREPARATION: None of the raw material used is cooked, but is added to the beater as purchased, and with only a casual sorting.

MAKING AND FINISHING: This paper is made on a cylinder machine of one or more cylinders, depending on grade and weight of product. The most important point is not to run too dry, as this greatly decreases the strength and fold of the sheet. The paper is sold in rolls, or is cut into sheets and wrapped in bundles.

8. Bond Paper.—A writing paper of light to medium substance, hard sized, and finish suitable for writing with pen or typewriter; originally designed for use where strength and durability are essential, such as government bonds, legal documents, wills, insurance policies, etc. Now made in many grades, fairly true to type, to meet more general needs, particularly in commercial work, such as letter heads, business forms, checks, etc.

MATERIALS: The furnish for bond varies from all rag to all sulphite, with various mixtures in between. For instance, in a 50% rag bond made from new colored rags and bleached sulphite pulp, the rags are sorted, cut, and dusted, cooked 10 hr. in a rotary at 35 lb. steam pressure with 10% lime and 2% soda ash, washed, and bleached with 40 lb. of bleaching powder per 1000

lb. of rags. The rags are furnished first to the beater, the sulphite 2 hr. before dumping. Beating takes 4 hr., but may take 15 hr. or more for all-rag paper. Loading is very seldom used. This paper was sized with 1.2% rosin and 1.0% alum in the beater, 1.5°Be. converted starch gum on the paper machine, and 3°Be. glue in the size tub on the air-drying machine. The Jordan was set fairly hard. Stock for bonds is kept fairly long.

MAKING AND FINISHING: Bond paper is made on a Fourdrinier with 65-mesh wire, 4 suction boxes (5 in. vacuum), suction couch (12 in. vacuum), dandy roll with watermark, 2 presses, steam pressure 2 lb. (using 3 pounds per pound of paper); speed, 250 f.p.m., may vary from 100 to 300 f.p.m., depending on weight and grade of paper. Most sulphite bonds are either plain wove or are marked with rubber stamp on last press or first dryer, and run at speeds up to 600 f.p.m. They are finished by one nip of 8-roll calender; this practice will vary greatly, depending on the mill and the product desired. Much high-grade bond is still loft dried. Higher finish is given on sheet calender or plater, and the paper is sorted, wrapped in reams, and packed in cases.

9. **Book.**—An uncoated printing paper for books, magazines, etc. Book papers are generally divided into the following classes:

M.F. (machine finished); any M.F., or mf., finish may be from very low to very high, but it is all done on the paper machine as the paper is made.

E.F. (English finish); a high machine finish, smooth in texture, but not the highest gloss possible.

S.C. (supercalendered); or S. and S.C. (sized and supercalendered); final finish obtained on supercalender, and may be high, low, or medium.

Bulking (featherweight); a paper with high thickness for weight.

Antique; rough surface—no finish at all.

Offset; used for lithographing print; hard sized, and usually tub sized.

Coated; dull and high finish; folding.

Special grades.

Even formation, opacity, and good, uniform finish are desired on book papers. Basis weight, 25 × 38—500, is 30 to 120 lb. per ream.

MATERIALS: M.F., E.F., and S.C. book are usually made from a mixture of bleached and unbleached sulphite, bleached soda, and bleached or unbleached magazine or book stock, the per cent of each depending on the location of the mill and the availability and price of raw materials. The normal furnish for these grades may be taken to be 25% to 40% sulphite, 0% to 75% soda pulp, and 0% to 75% bleached magazine stock.

PREPARATION: The old magazines or books are sorted to remove paper containing groundwood, covers, metal, and foreign material, and are cooked in either open or closed cookers, with soda ash about 2% to 5% on the weight of the stock. Caustic soda may be substituted for soda ash, but is not recommended, as it is hard to handle, owing to high caustic strength. After cooking, the stock is washed free from ink and may be bleached with about 2% bleaching powder in solution; it is again washed, and then usually sent to a storage chest, from which it is pumped to the beaters. The loss in this process is from 25% to 50% of the original weight of material, depending on raw materials and method of treatment. Sulphite pulp, soda pulp, and bleached paper book stock are furnished in proper proportions, together with size and color. Beating is fairly light, and is more in the nature of a thorough mixing than real beating, the beating time being from 1 to 4 hr., generally about 1 hr. Loading is added in amounts from 5% to 40%, depending on the product required, and the material used is a good grade of clay or kaolin, previously mixed in water to a thin milk, and strained. The amount of clay varies from 5% to 40% of the furnish, depending on the amount of ash desired in the finished sheet and the effectiveness of the save-all system. Opaque pigments are used up to 1% to increase the opacity of the lighter weight book papers. Book paper is made 'slack sized,' that is, not suited to pen and ink; therefore, small amounts of rosin size (not over 1%) and alum (not over 2%) are used. Most book papers are made in white, natural, and India colors, tinted with blue, red, or yellow. They are usually put through Jordans with enough water to keep the stock as free as possible, and they are cut short for good formation. Jordan horsepower consumption will run from 60 to 300 hp., depending on size of Jordan engine.

MAKING AND FINISHING: A Fourdrinier is used with wire of 70 to 80 mesh; speed, 300 to 600 f.p.m.; consistency, 0.5% to

0.9%; vacuum on suction boxes, 4 to 6 in.; steam on dryers, 0 to 10 lb. For M.F. and E.F. finish, use smoothing rolls and one or two stacks of machine calenders. Variation in finish is obtained by character of surface of press felts, amount of pressure at press rolls, smoothing rolls, and calender rolls, and moisture content of the sheet; character of stock and the formation on the wire are also important. E.F. should be a very closely formed sheet, alike on both sides, and a uniformly smooth, but not too high, finish. M.F. is not usually as well closed as E.F. S.C. should be fairly well closed, and may be run with or without smoothing presses. It is calendered on paper- or cotton-roll supercalenders, two or more times through the supercalender stack; it should have a uniformly high-finished surface, and the paper must be dry enough not to crush or blacken on the supercalenders. M.F., E.F., and S.C. are all shipped in rolls or are cut into sheets and packed in bundles, frames, or cases, as ordered. Book paper packed in cases has markers between reams.

Bulking paper is usually made of 50% to 80% soda pulp and the rest sulphite; there is little or no loading. The highest grades may contain 75% to 100% cotton linters or old rags. For cheaper grades, groundwood is also used. This stock is beaten very little, and is kept as free as possible, for bulk. It is run so as to bulk on the machine (bulk being the thickness of 500 sheets as determined with a bulking scale), and the bulk must be kept uniform and as great as possible. Special finish felts are used, with light pressure at the press rolls, to retain bulk, and only one nip on calenders and no smoothing press.

Coating stock is usually made of 30% to 60% sulphite, the rest being soda pulp or magazine stock. Stock is beaten to get a fair degree of strength; it is sized with 1% to 2% rosin, and alum is added to give a pH of about 5.0 to 5.4. The finished paper is usually somewhat slack sized. Coating paper is colored white, or is tinted to correspond to finished coated paper. A well-closed sheet is wanted, smooth and free from fuzz. It is finished on the machine, using machine calenders, and is rewound on rolls for use on the coating machines. Some coating stock contains a proportion of rags, for folding qualities.

Offset paper is usually made with a furnish similar to regular book, but is not so heavily loaded. Stock must be well brushed, so the resulting sheet is free from fuzz, and the surface must

not 'pick' or 'pull.' It is slightly sized with 0.5% to 2% rosin, and alum for a pH of 5.0 to 5.4. It is made on a Fourdrinier with a 70-mesh wire at speeds of 100 to 400 f.p.m.; sometimes tub sized with starch or gum, and given 2 to 4 nips on machine calenders, but not high finish; smoothing rolls are also used. Shipped usually in reams, accurately trimmed square on all four sides, cased with ream markers; or, it may be shipped in rolls. Offset paper must not wave or curl; trimming must be very accurate, to avoid trouble with register on the printing press. The sheet must lie flat, and must be finished alike on both sides.

Special grades of book are very numerous; some are made with varying proportions of rags, and are watermarked; they are either laid or run with specially woven felts, to produce special surfaces.

10. Bristol.—Called also *bristol board, mill bristol, index bristol, rope bristol,* and *wedding bristol.* A heavy paper or light board, 0.006 in. or more in thickness. Used for show cards, drawings, indexes, menus, name cards, etc. Usually made solid on a Fourdrinier or a multicylinder machine. If made on a cylinder machine, it may be a filled board. Wedding bristol is generally made by pasting together two or more sheets. Basis weights are as follows: *Mill and rope bristols,* 100, 120, 140, 160, 180, and 200 lb. per ream, 22½ × 28½—500; *index and wedding bristols,* 110, 140, 170, and 220 lb. per ream, 25½ × 30½—500; wedding bristol may also be made to gauge or thickness and be designated by 'ply,' as 2-ply, 3-ply, 4-ply, 5-ply, 6-ply, and 8-ply; *bristol board* is made to gauge or thickness, like wedding bristol, and in addition to the thicknesses made for weddings, may include 10-ply, 12-ply, and 14-ply.

MATERIALS: Made of mixtures of sulphite and soda pulps (from 40% to 85% sulphite), with 5% to 20% agalite or china-clay filler in cheaper grades. Higher grades contain up to 100% rag; some hard shavings may also be used.

PREPARATION: Rags require 6 to 10 hr. beating; wood pulp, 1 to 3 hr. A fairly short, free stock is wanted, to give a well-closed sheet. All the bristols are hard sized, to make them suitable for pen and ink, and may have up to 1% to 4% silicate of soda and 3% to 10% beater starch.

MAKING AND FINISHING: Usually made on Fourdrinier (see first paragraph), with 70-mesh wire, 5 to 6 in. vacuum on suction

boxes, and 14 to 18 in. on suction roll; consistency of stock, 0.5% to 1%; speed, 50 to 150 f.p.m., according to weight and slowness of stock. Bristols are usually made with a wove dandy. The use of a smoothing press will help to secure a finer grained surface. Some grades are tub sized with starch or glue. A cylinder machine of 2 or 3 cylinder molds may be used, the speed being 100 to 150 f.p.m., depending on weight of sheet. The paper is supercalendered, cut, trimmed, hand sorted, and wrapped in 100-sheet packages. In addition to white, the colors are: buff, canary, green, ecru, blue, salmon, gray. A stiff sheet having a good printing surface is wanted.

11. Building Paper.—A general term applied to a class of thick, bulky papers made of old stock (rags, wool, mixed papers, etc.) and sometimes mixed with asbestos. This class of papers is used in general construction work, and it may be converted into such products as roofing, tarred felt, etc. Building paper includes: *sheathing papers*, used to insulate houses and overcome wind seepage; *felt papers*, used unsaturated for houses to add to heat insulation, or used after saturating with tar and asphalt as a roofing material; a special felt, called *deadening felt*, is used for deadening sound by placing in walls and floors of houses; special felts are also made for lining under carpets and rugs.

MATERIALS: Includes all kinds of waste-paper materials.

PREPARATION: Fed into beaters, or broken up sufficiently to run over a cylinder machine.

MAKING AND FINISHING: Always made on a multicylinder machine and shipped in rolls. (See also Felts—deadening and carpet lining—under Boards, Part 2.)

12. Butcher's Manila.—A yellow-colored wrapping paper, made of partly cooked straw pulp; it is well sized, and is used for wrapping meat. This class of paper has almost disappeared from the market—the cheap wood manilas have taken its place.

MATERIALS: Partly cooked straw pulp; cooked in rotary boilers with 10% to 20% lime.

PREPARATION: Cooked pulp may be broken up in the beater without washing.

MAKING AND FINISHING: Made on a 1- or 2-cylinder machine, cut into sheets, and wrapped in bundles for sale.

13. Carbon Tissue.—A tissue paper of 4-, 5½-, 7-, and 10-lb. weights (20 × 30—480), of close texture, smooth surface, free from pinholes, and used as the basis for carbon copying paper.

MATERIALS: The best grades of carbon tissues are made from new cotton and linen rags and manila hemp. Some sulphite pulp may be used in the cheapest grades.

PREPARATION (See under Bible Paper, Art. **6**): The preparation of half-stuff for carbon tissue is the same as for bible paper. In the final beating, however, there is a great difference, since strength is a very important factor; hence, there is little cutting action, but a long brushing of the fibers, which may take from 20 to 30 hr. The paper is very lightly sized, and contains not over 5% ash. The sheet must be free from pinholes and of extremely close formation.

MAKING AND FINISHING (See Art. **6**): The paper-machine equipment is the same as for bible paper. The paper is finished in rolls, and wrapped for shipment to the place where the carbon coating is applied.

14. Carpet Lining.—A soft, thick, spongy building paper, plain or indented, used for insertion between floor boards, and under carpets and rugs. (For details, see Building Paper, Art. **11.**)

15. Cartridge Paper.—(*a*) This paper is a manila wrapping paper, from 50 to 80 lb. in weight for 24 × 36—480, sometimes waxed on one side; used as containers for dynamite or other explosive material. (*b*) It is a 3-ply or 4-ply paper produced in a particular manner and used to make shotgun shells; the shells must be perfectly cylindrical, both inside and outside. To secure this effect, it is necessary to use a sheet of paper having two opposite sides tapered in thickness. The sheet of paper is wound on a steel mandrel, so the tapered edge of the sheet is parallel to the axis of the paper tube.

MATERIALS: Rag or a mixture of rag and sulphite pulp is used.

PREPARATION: Beating and sizing are important, and depend on certain qualities required by each manufacturer of shotgun shells.

MAKING AND FINISHING: To produce a sheet of paper described under (*b*) above, it is necessary to have a 3- or 4-cylinder machine. The first cylinder makes a sheet of lightweight and the full width of deckle desired. The second, third, and fourth cylinders each

have deckles spaced at regular intervals across the face of the mold; these deckles are widest on the No. 4 cylinder, narrowest on the No. 2 cylinder, and a little wider on the No. 3 than on the No. 2 cylinder. Cylinders 2, 3, and 4 each pick up a series of strips of pulp, their width being greatest on cylinder 2, least on cylinder 4, and between these limits on cylinder 3. These strips are deposited one on top of the next, as in any cylinder-machine operation. After drying, the paper is slit at a point in line with the middle of each line of deckles. These paper strips are then cut to the desired lengths and packed in bundles or cases for shipment. The resultant sheet of paper, if made 4-ply, consists of 4-ply thickness over part of its area, 3-ply over more of its area, 2-ply over still more of its area, and 1-ply over all its area. The tapered edge is parallel to the machine direction of the sheet.

The manufacture of manila wrapping paper is described under Manila, Art. **44**.

16. Catalog Paper.—A lightweight, opaque book paper, made of old papers and groundwood pulp, with some soda and sulphite pulp added. Opaque pigments (about 1%) are added to the beater to increase opacity. Used principally for mail-order catalogs and directories, requiring a high-finished, well-sized sheet. Weight varies from 36 to 56 lb. per 1000 sheets, 24 × 36.

MATERIALS: Groundwood, 35% to 50%; old papers, 35% to 40%; unbleached sulphite, 30% to 10%; soda pulp may be used instead of groundwood for the better grades. Loaded with clay or talc, about 10%.

PREPARATION: Beaters are used only for mixing, and stock is brushed light in the Jordan. Sized with 1% to 2% rosin; 1.5% to 3% alum. Colored white, canary, golden-rod, pink, and tan. Basic colors are used.

MAKING AND FINISHING: Fourdrinier machine used, with 70-mesh wire; dandy; 6 to 7 suction boxes, and suction couch and suction press. Stock is slow and fine. 0.3% to 0.8% consistency at headbox; 7 to 9 in. vacuum on boxes, 16 in. on suction couch, and 21 in. on suction press; 3 to 5 lb. steam pressure on dryers; speed, 500 f.p.m. for 36-lb. to 300 f.p.m. for 56-lb. sheet; these speeds are fair average figures. Finished on machine calender, 8 or 9 rolls; slit to size, and rolls wrapped. Some catalog paper is cut in sheets and packed in bundles.

17. Chart Paper.—A writing paper made similar to a ledger paper, and used to print nautical charts, maps, etc. Best grades are made of 100% new rags, while lower grades are mixtures of rag and bleached sulphite. For the best grades, strength and high folding quality are most essential, also, smooth surface without gloss; good erasing quality; suitable for pen and ink, plate printing, and lithographing. Chart papers are usually 40-, 44-, 48-, and 52-lb. for 17 × 22—500.

MATERIAL: Same as for ledger paper, Art. **42.**

PREPARATION: Same as for ledger paper.

MAKING AND FINISHING: Same as for ledger paper.

18. Cigarette Tissue.—A tissue paper that is unsized, of close texture, and free from pinholes. Generally made from new cotton and linen rags, with some manila hemp, and used as a wrapper for tobacco in the manufacture of cigarettes.

MATERIALS: New cotton and linen rags, shoe waste, and sometimes some manila hemp. Rice straw is used in some grades, but always with some cotton and linen rags. This paper is heavily loaded with chalk (calcium carbonate), and may be light sized with rosin and alum. Ramie fiber may be used in small quantity with cotton and linen.

PREPARATION: Extra care must be used in sorting the material. Cooking is conducted in rotary boiler at relatively low pressure and temperature. The cooking alkali is usually about 5% soda ash, and some mills secure best results with caustic soda. Lime should not be used. Washing, bleaching, and conversion to half-stuff must all be done with care, in order not to cause excessive hydration.

MAKING AND FINISHING: The first beating from half-stuff must guard against excessive hydration and yet maintain length of fibers sufficient to insure needed strength. The beating time varies from 15 to 30 hr., depending on the characteristics of the individual beater. All cigarette papers are heavily loaded, and the best grades will show up to 30% of ash, equivalent to 35% to 40% added. Only chalk is added, and of the finest (almost colloidal) grade. The function of chalk is to slow up the combustion of the cigarette paper; this is its chief function, but there are other factors of importance. The stock being very slow must be screened through screens of ample area, as the slots (flat

screens) must not be more than No. 8 cut (0.008 in.). The Fourdrinier machine is used, with a wire of 100 to 120 mesh. Special weaves of wire cloth are used where needed to secure certain effects in finish and surface. The machines are narrow (50 to 60 in.), and operate at 100 to 150 f.p.m. Special 'pickup' felts are used at the couch roll, and again to transfer from the last press to the first dryer. Drying must be very gradual and at low temperatures. Finishing is generally done on the paper machine with 2 or 3 nips of the calenders. Some papers are watermarked, but this is really an embossed mark, as it is done on special embossing presses (web presses). The paper is finally slit into widths of about 30 mm. (approximately $1\frac{1}{4}$ in.), and is wound on cores. The finished bobbin, as it is called, will contain about 3500 meters (11,500 ft.), and will weigh about 5 lb. Bobbins are wrapped and cased for shipment to manufacturers of cigarettes.

19. Coated Paper.—A printing paper having a coating of clay or other fine material, and which can be given a very smooth finish. The paper base is described under Book, Art. **9.** *Blanks* (cardboard), with groundwood or news filler, and lined on both sides with book paper and coated on one or both sides, are *known as coated blanks, coated litho blanks*, and are used for calendars, advertising cards, etc. The body paper should be colored the same as the coating to be applied, usually, white, blue, green, India, tan, buff, canary, gray. Coated paper is used for illustrated books, circulars, catalogs, magazines requiring fine halftones, cigar bands, etc.

CHARACTERISTICS REQUIRED: Very smooth surface; strong coating, one that will not pick up, crack, or dust off; good printing qualities. Strength is important, but is secondary to the other characteristics mentioned.

COATING MIXTURE: Color for high finish, coated paper consists of:

(1) Casein—Casein dissolved at 130°F. with alkalis, as borax, soda ash, caustic soda; solution cooled.

(2) Pigments—40% satin white, 60% coating clay: about 13% casein on dry weight of pigments.

(3) Coloring—Tinted with alkali-proof blue, red, or yellow; ultramarine is practically the only blue used.

MAKING AND FINISHING: The pigments are made into a smooth paste with water; casein is added, and the mixture is stirred for at least ½ hour; colors are added, and the suspension is screened. The paper is coated on one side at a time; dried on a festoon dryer at 120°F. (See Section on *Coated Paper* for details.) Paper is reeled under tension, and edges are trimmed after second coat. Calendered in stacks with alternate cotton and steel rolls, run through 3 times—first time with no weights; second and third times with weights. Cut on rotary cutter, and trimmed square on 4 sides with trimmer. Sorted by hand into perfects, seconds, and thirds; packed loose in lined cases, with markers between reams.

SPECIAL REMARKS: Many variations are possible in this paper. Stock may contain unbleached sulphite (to lower cost) or rag (to increase strength). As made by different companies, it contains from 100% sulphite to 30% sulphite and 70% soda. Loading may vary from none to 300 lb. of clay per 1000 lb. of stock. Almost any ratio of clay to satin white may be used, from 100% clay to 50% clay and 50% satin white. Increasing the satin white raises the finish. Coated sheet may be brushed before calendering, to give it higher finish and smoother surface. Sheet may be coated on double coater, and floated on air until bottom side is dry; this gives a lower quality of sheet than the other method.

Coating for dull-finish paper consists of: (1) casein, as above; (2) pigments (100% blanc fixe, 13% casein as adhesive); (3) coloring, as above; mixing. This grade is made in various ways. Calcium carbonate, calcium sulphate (both sold under various names), and clay are often used with or in place of blanc fixe, to lower the cost. Starch or glue can be used as binders instead of casein, or to replace a part of the casein.

Characteristics required are a strong coating, good printing qualities, and a very smooth surface free from glare.

20. Copying Tissue.—A term applied to a group of tissue papers that are slack sized, soft in texture, and of considerable strength, for use in letter-press work, or for special manifolding purposes, such as for railroad waybill copying. The best grades are made with much the same materials and care as in making carbon tissue. Japanese tissue is used made from mitsumata

fiber. The copying tissues are almost obsolete, owing to substitution of carbon-tissue copies in place of the old letter-press copy.

MATERIALS: Cotton, linen, manila hemp, old rope, etc.

PREPARATION: Sorted, cut, dusted, and cooked in rotary boilers with lime and soda ash (about 10% of lime and 3% to 5% of soda ash). Cooking time, about 10 hr., at 30 to 40 lb. pressure. The stock is well drained, then washed and broken down to half-stuff; it is then bleached and dumped into drainers.

MAKING AND FINISHING: The final beating operation is best carried out in small beaters and dull tackle. The beating will take from 15 to 20 hr., as maximum brushing-out effect must be secured. Strength is most essential. The sheet has little or no rosin size, and a very small amount of alum, to maintain a pH of 5.0 to 5.5. The stock is screened through No. 8 cut plates (0.008 in.) in diaphragm screens, and is run over a single-cylinder machine having a wire mesh of 80 to 100. Speeds of 75 to 150 f.p.m. are maintained. The Fourdrinier machine can be used, of course, but it has been the custom to use the cylinder machine in the United States. Special pickup felts are used to transfer from the press to the dryers. Drying must be slow, so as not to burn the sheet. Calendering is generally light, as a low finish is desired. The paper is finally cut into sheets (usually, on a tissue reel) and ream wrapped, with cardboards top and bottom; these packages are then cased for shipment. Basis weight is 7, 8, 10, and 12 lb. for 20 × 30—480.

21. Cover Paper.—A relatively strong and heavy paper, made in many finishes and fancy designs, some treated to imitate leather; used principally for the protection of stitched or stapled literature, photographs, etc., and for programs and menus. Cover paper should be tough and durable, with good folding quality, and take ink and embossing. Common shades are white, blue, brown, India, green, gold, red, and gray.

MATERIALS: Rags of all grades, from new cuttings down to and including thirds and blues; sulphite, bleached kraft, hardwood sulphite, groundwood, and soda are also extensively used for regular grades. Loading of various kinds is generally used.

PREPARATION: Rags cooked with lime and soda ash, washed, and bleached. Beat 3 or 4 hr., brushing out rags 1 or 2 hr. before adding sulphite; beat fairly free, and brush light to fairly heavy in

Jordan, depending on stock. Size with 2% rosin, 3% alum, and 1.5% silicate of soda. One mill used 3% starch.

Making and Finishing: Made on Fourdrinier, 70- to 75-mesh wire; speed varies with weight, about 150 f.p.m. for 130-lb. paper, 20 × 26—1000; consistency, 0.7% to 1% at headbox; 5 to 8 in. vacuum on boxes, about 15 in. on suction couch; smoothing rolls used, but generally not all the rolls of the calender, except on very high finish; supercalendered or plated for special finishes; heavy-weights are pasted. Wrapped in ream or half-ream packages, and packed in bundles or cases.

22. Crepe Paper.—A thin paper, treated to give the effect of crepe, which imparts to it a feeling of softness, and stretching and absorptive qualities; it is used as napkin, toilet, and decorative paper.

Materials: Bleached sulphite pulp for white or tinted papers; unbleached sulphite or sulphate for natural colors; groundwood may be added in cheaper grades.

Preparation: Beaten 1 to 2 hr., depending on hardness desired in the paper. A beater producing 6 to 7 tons per day will require 50 to 60 hp. Decorative and toilet crepes are well sized, and are tinted with blue and pink for white paper, with auramine for manila, etc. Stripe effects are produced by coloring on the paper machine. The Jordan is set very light—for brushing only.

Making and Finishing: A Fourdrinier or Yankee machine may be used, with a wire of 70 mesh or finer; 1 to 2 suction boxes are sufficient; some grades are made on a cylinder machine. The speed may be 400 f.p.m.; consistency of stock, about 0.5% at flow-box; vacuum, about 5 inches on suction box. One set of presses is used; steam pressure, up to 8 lb. on the dryers, using about 3¼ lb. of steam per pound of paper. The cheaper grades are creped by scraping the still damp paper from a dryer roll with a doctor, drying on another roll, and winding without tension. Finer crepes are wound in rolls and creped on an auxiliary machine: the paper is moistened sufficiently to make it stick to a smooth roll, from which it is scraped in such a way as to cause wrinkles while the sheet is being drawn away and wound. Toilet paper and roll towels are slit, perforated, and rewound on a separate machine. Decorative crepes are slit and rewound in 10-ft. lengths on cores; the cores are withdrawn, and the paper is

flattened and wrapped. Interfolding machines are used for most towels and for some toilet papers. Packages are made by winding the paper on a collapsible reel, cutting to size, punching, and inserting wire hooks. Decorative crepes are packed 12 in a carton; towels, in rolls or in packages of 100 to 150 sheets, with 25 or 50 rolls or packages to the case; toilet papers, 100 rolls or packages to the case.

23. Deadening Felt.—The term deadening felt is applied to those felts that are used in construction for deadening sounds, and under hard-surface floor coverings as a protection against uneven floors; they may also be used as insulation against heat or cold. (See under Building Paper, Art. **11**, for more details.)

24. Drawing Paper.—A writing paper of close texture, firm surface, not unpleasant to the touch, but with sufficient tooth or grain quickly to take lead-pencil marks; finished slightly, without sheen or gloss; good erasing quality; hard sized. Best grades are for original drawings of maps, architect's plans, engineer's plans, etc. The cheaper grades are used in schools for use in kindergarden work and for more advanced classes; also for pencil drawings that are to be traced.

MATERIALS: New cotton rags for best grades; lower grades may contain old rags, hardwood sulphite, and mixtures of sulphite and soda pulps; the cheapest grades, used for school work, are generally made of about 50% to 75% groundwood and 50% to 25% unbleached sulphite; all are sized very hard with rosin and alum. Some loading, like kaolin, up to 15%, is used in the lower grades.

PREPARATION: New rags are used, either raw or cooked in rotary boiler with 2% to 5% soda ash, followed by washing and bleaching to the desired degree of whiteness. Old rag and rope are usually cooked with some lime, about 5%, with 2% to 5% of soda ash, followed by washing and bleaching.

MAKING AND FINISHING: The final beating operation depends on the raw material used. The stock is cut short and with sharp tackle in both beater and Jordan, which helps to give a dense, compact sheet that, when heavily sized, will give best erasing quality. The higher grades are usually tub sized with glue or gelatine, and may be loft or air dried. The beater stock is screened through No. 10 or No. 12 cut plates (0.010 or 0.012 in.)

for diaphragm screens, or 0.018- to 0.020-in. slots for rotary screens. The Fourdrinier machine is used, though some of the manila or rope-stock drawing papers are made on cylinder machines. The finished surface is always somewhat rough, but should be fine grain; this effect is best obtained by special felts, suction-couch roll, and careful drying and calendering. The finished paper is sold in both rolls and sheets, suitably packed. There is a variety of weights and sizes, depending on the trade, and the colors are white, cream, or buff. The average weights for the best grades are 26, 34, 40, and 48 lb. for 17 × 22—480, in varying sheet sizes. The manila drawing papers weigh 80, 90, and 100 lb. for 24 × 36—500, and are sold in rolls. All roll drawing papers are in the following widths: 30, 36, 42, and 48 in. The groundwood school drawing papers are 56 and 64 lb. for 24 × 36—500, and are sold in small-cut sizes.

25. Duplex Paper.—A paper made in two layers, the two sides being of different colors, or the layers may be of two different grades of stock; usually made on a two-cylinder machine; but a duplex paper can be made on a cylinder and Fourdrinier combined, there being 5 or 6 of these in North America. Used for cover papers, boxboard, paper bags, envelopes, etc. Should have a good tear and pliability, and a medium high finish for bag, envelope, and cover stock.

RAW MATERIAL: Originally, duplex bag papers were made of rope and jute stock, put together on a 2-cylinder machine, with one side colored a deep blue, red, green or other deep color. The best grades are still made this way, though much duplex wrapping and bag paper is now being made of kraft pulp, both bleached and unbleached. Some mills still use a certain amount of rope and jute stock mixed with their sulphite or sulphate pulps. Duplex cover papers are today largely made of sulphite or sulphate or both, or both with an addition of rag or rope stock to meet particular conditions.

PREPARATION: Sulphite and sulphate pulps used to make bag, cover, or envelope papers are beaten for high strength and flexibility and a strong tear. These papers are hard sized, and are usually of a high machine finish. In special cases, they may be given a high supercalender finish, especially the duplex cover papers. The old-fashioned duplex flour sacks, usually colored

blue on the inside, were of a very high grade. The blue lining of the sheet was 100% rope and jute stock, beaten for 5 to 10 hr., depending on the kind of beaters used. Beating was continued until stock was very slow, and yet of good fiber length. The outside, the natural color side, was a mixture of 25% to 50% sulphite, and the remainder was rope stock. This was also beaten for high strength, but not so slow as the blue liner sheet. The blue liner was usually $\frac{1}{5}$ to $\frac{1}{3}$ of the total weight of the duplex sheet. Both sides were given a 'medium' sizing, since a hard sizing was supposed to make a brittle sheet.

Making and Finishing: The making and finishing of a duplex sheet presents about the same problems as most of the other papers, except that for duplex bag, cover, and envelope paper, great care must be exercised to secure a good bond between the two plies of the sheet. This means keeping both sheets as wet as possible at the point of contact with each other, and so graduating the pressing out of the water that this action will at no time be excessive, causing crushing. The wire mesh on both cylinders, or on cylinder and Fourdrinier, should be 65 or 70, preferably 70, since this results in a saving of fiber and the sheet is of closer texture. Some mills prefer 50 mesh on the cylinders, but this is not considered as regular practice. The number of suction boxes on the Fourdrinier, like many other details, is dependent on the speed that can be used, and this, in turn, depends largely on the number of dryers and their total heating surface.

The rope duplex papers are made in the following standard weights per ream of 24 × 36—500: 50, 60, 70, 80, 90, 100, 125, 150, 200, 250, 300, and sometimes 315 lb. The duplex envelope papers are also made in the same weights.

26. Envelope Paper.—Paper for envelopes is made in several grades, according to the use of the product. It may be made of various percentages of rag and sulphite for stationery; groundwood (manila) and sulphite for some kinds of office correspondence; or kraft paper for clasp envelopes, etc. This paper should have a good writing and printing surface, proper sizing to take the gum, and good toughness and folding quality.

Making and Finishing: A rag paper (15% rag and 85% sulphite) is beaten 3 or 4 hr., and jordaned light. In the furnish,

about 20% agalite, 3% starch, some silicate of soda, 1¼% rosin, and alum. An all-sulphite sheet is beaten about 2 hr., and is jordaned fairly hard. About 12% talc is used, and 2.4% size. A manila envelope is made of sulphite and groundwood; the sulphite is furnished first, and the whole is beaten an hour; 1.6% rosin is used, and alum is added according to a pH test; loading may be used. Colored with auramine or a fast yellow. It is heavily calendered. Machine speeds vary from 175 to 200 f.p.m. on 32-lb. folio to 350 to 375 f.p.m. on 16-lb. folio.

27. Featherweight.—A general term indicating a lightweight paper; used in connection with such papers as lightweight bulky book paper, thin opaque writing paper, and lightweight tissues. For details, see under the more specific names.

28. Filter Paper.—A porous, absorbent paper, used in filtering liquids in laboratories or in various industrial processes. Ordinarily made of rags and refined chemical wood pulp, but the better grades are made of selected rags; quantitative filter paper (used in the chemical laboratory for quantitative analysis) is acid-washed in hydrochloric and hydrofluoric acids.

MATERIALS: Best grades are made of new white cotton rags, beaten to half-stuff without cooking, and given a very mild bleaching and washing. The first beating is with sharp tackle, bronze bars, and copper-lined beaters and chests. Maximum freeness must be obtained, and the sheet felted in the loosest possible manner. The best grades are still made on hand molds, as machine-made papers are too dense in texture. The sheets are made without loading, size, or alum, since a pure cellulose product is most essential. The first step is to wash in successive baths of hydrofluoric acid and hydrochloric acid, to remove all traces of lime, silica, or other non-metallic compounds or particles that may have become mixed with the fibers. After washing in distilled water, the sheets are dried, cut to size, and packed in carefully wrapped packages, for use in the chemical laboratory. It was formerly stated that all the best filter papers were subjected to a six months' freezing process, but investigation proved this untrue. The ordinary grades of commercial filter paper are made of old rag and sulphite pulp. The rags are handled in the usual way in the rotary boiler, with subsequent washing and cooking operation. The stock is beaten free and short, and

run over the paper machine without loading, size, alum, or other materials added.

MAKING AND FINISHING: The Fourdrinier machine is used, and the sheet is handled with the least amount of pressure; this means suction-couch roll, light press roll, special felts, and slow drying. No calendering is permitted. The paper is cut into sheets, wrapped in packages, and cased for shipment. Commercial grades of machine-made filter papers have the following ream weights; 16, 20, 25, 30, and 35 lb. for 20 × 20—500.

29. French Folio.—A lightweight writing paper, hard sized and high finish; used for making proofs, for second sheets, for multi-copy work, and for various purposes where a lightweight paper is required. It is made in white only, and of 100% bleached sulphite pulp. The pulp is beaten to produce a slow stock of maximum strength; final finishing is done on a paper-roll supercalender.

The grade known as French folio or white French folio is gradually being replaced by what are called *manifold papers*. French folio was made 17 × 22—480, in weights of 7, 8, 9, and 10 lb.

30. Fruit Tissue (Fruit wrap).—A medium grade of wrapping tissue, made of bleached and unbleached sulphite or sulphate pulp and groundwood, and used for protecting and preserving fruit for shipment; must be strong enough to twist or wrap about large fruit; some grades may contain up to 25% of groundwood pulp.

PREPARATION: Beaten for a slow stock, and small amounts of size and alum are added.

MAKING AND FINISHING: Generally made on a cylinder machine, with suction presses. Speeds up to 400 f.p.m., if machine equipment is in good condition; very little calendering required; cut into sheets or slit into rolls for shipment. Weight, 5 to 12 lb. for 20 × 30—480.

31. Glassine.—A transparent, or semi-transparent, grease-proof paper; used as a wrapper for meat, fish, candy, tobacco, and for making bags, window envelopes, etc.; it is required also to be tough, non-porous, and printable.

MATERIALS: Made of sulphite pulp, bleached or unbleached, according to product wanted; Mitscherlich pulp is preferred by some mills.

Preparation: The stock is beaten 4 to 6 hr. with stone (lava) roll and bedplate; very little loading is used, also very small amounts of rosin and alum sizing. White paper is tinted with basic blue; other shades, as red, chocolate, blue, green, are dyed with direct or acid colors, fast to light. Brushed out well in Jordan, to get very slow stock. Plasticizers, as glycerine or sugar, are added for flexibility.

Making and Finishing: Fourdrinier machine speeds vary from 225 to 300 f.p.m., depending on freeness of stock and weight of sheet. Fairly heavy suction is used; very light finish is given on machine calenders. The paper is dampened and put through a special supercalender; some papers are given a special surface by using embossed rolls, often supercalendering, thus obtaining the attractive cobweb and watered effects frequently seen in candy-box wrapping, outside covers of pamphlets, etc. Weights are 18, 20, and 25 lb. for 24 × 36—500.

32. Granite Paper.—A general term indicating a paper that is mottled to imitate granite by adding fairly long fibers of a color differing from the color of the body of the sheet; generally refers to cover, blotting, wallpaper, and some fancy writings.

Materials: Raw material may be any combination of papermaking fibers; old black cotton stockings, beaten to leave fibers of maximum length, when added to beaters of white pulp, will produce a so-called gray granite effect. Great variation in effects may be secured in granite papers, but their novelty is largely gone.

33. Greaseproof Paper.—A term used to indicate a quality possessed by certain papers, such as vegetable parchment and glassine, that are impervious to oil or grease; generally used for wrapping articles that are oily or greasy—waxed papers are not greaseproof. Also includes greaseproof wrappings. (For details, see Glassine, Art. **31.**)

34. Greaseproof Wrapping.—A wrapping paper made of sulphite pulp, usually Mitscherlich or other strong sulphite; beaten until thoroughly hydrated; also, thoroughly jordaned. This paper resembles the vegetable parchment made by chemical processes; but it is not as strong when it is wet as when it is dry, as is the case with vegetable parchment. It is used for wrapping greasy food products, and it is also the base from which glassine

is made. Also called imitation parchment, pergamyn, and parchmoid. (See Glassine, Art. **31,** for details of manufacture.)

35. Halftone News.—A grade of newsprint paper possessing a high finish, and of a little heavier weight than regular newsprint grade; it may also contain small amounts of filler; must have a high finish, in order to print halftones clearly. Basis weight, 34 lb. for 24 × 36—500. Produced like regular newsprint, except as previously noted.

36. Hanging Paper.—Paper used for covering walls and ceilings, and for lining cheap trunks; it is generally classed with newsprint, but is a heavier sheet, and is made in a variety of weights: it must be fairly clean; sized so as to take paste without wetting through the coating and printing machines. It is regularly made in two grades, known in the trade as No. 1 and No. 2 hanging.

RAW MATERIALS: The best grade of this paper is known as *No. 1 hanging.* The tonnage used is small in amount, but it is decorated and often embossed for the most expensive wallpapers. The furnish is bleached soda and sulphite pulps, and sometimes bleached old-paper stock may be used, as well as 10% to 15% fine ground, very clean, groundwood pulp; in this grade, some clay or talc may be used as loading. Sizing is most important, and the sheet must be hard sized. The common method of testing is to cut a small piece of paper, about 2 × 2 inches square, and drop it on the surface of a pail of water that has been heated to 120°F. The paper must withstand the hot water for from 3 to 5 minutes before any moisture begins to soak through.

The regular or most used grade of hanging paper is known as *No. 2 hanging;* this grade is from 75% to 85% groundwood pulp, and the remainder is unbleached sulphite. The sheet is hard sized, to stand a 3- to 5-minute soak test as noted above. The stock must be fairly clean, and no heating or jordaning is required, as in making news and print paper. Loading is used, though the amounts must be small, as all wallpaper printers require a paper to be thick for weight.

The weight basis for hanging paper is in ounces, and it corresponds to the weight in ounces of a roll of wallpaper, which is 24 ft. long and 21½ in. wide. The weight in ounces multiplied by

4.27 will equal the weight on a ream basis of 24 × 36—500. The following tabulation gives the weight and roll width generally used:

Wt. in ounces	Wt. in lb. per ream of 24 × 36—500	Roll width, inches
9	38½	19¼, 19⅜, 19½
10	42½	19¼, 19⅜, 19½
11	46¾	19¼, 19⅜, 19½
12	57	19¼, 19⅜, 19½
14	59	——21½, 29
16	68	——29
18	77	——29
29	125	——19½, 21½, 29

PREPARATION: No special preparation of the stock is required, other than careful sizing.

MAKING AND FINISHING: Made on Fourdrinier, and at speeds up to 500 f.p.m. on lightest weight. A machine equipped to make a good news sheet is suited to making hangings. Very little calendering is required, since maximum bulk and a rough surface are desired. This paper is always put up in rolls, and in the widths shown in the above tabulation. The rolls are carefully wrapped for shipment on strawboard cores.

37. Imitation Parchment.—A paper rendered greaseproof and water resisting by prolonged beating; sulphite pulp is used. (See Glassine, Art. **31.**)

38. Insulating Papers.—A term rather loosely used in the paper industry to cover papers used for electrical-insulation as well as papers used for heat-insulation purposes. These two uses require entirely different papers; in fact, a relatively wide variation is required for each use. The following general subdivision gives the more important ones.

The **heat-insulation papers** include felt papers, asbestos papers, building or sheathing papers, the new type of wallboard, and the much-advertised light, thick, fluffing papers that are said greatly to reduce the thermal conductivity of a building wall or roof.

Electrical-insulation papers include condenser and cable-wrapping papers, used without impregnation with other insulating materials, and a wide variety of papers that are impregnated or treated to render them highly moisture resistant, and thus add to their electrical resistance. The impregnated, or treated, papers include the papers coated or impregnated with shellac, linseed oils, paraffin, bakelite, and similar products; and the treated papers comprise vulcanized fiber, vegetable parchment, viscolized fiber, and mechanical parchments.

The above groups, under the general term of insulating papers, include every kind of fiber in common use, and a wide variation in method of manufacturing and in the finished product. The diagram on page 28 may serve to give a clearer understanding.

The following description is only a brief statement pointing out some of the more important of these papers and their characteristics: The **felt papers** are thick spongy sheets made from old cotton and wool rags, or, for the lower grades, containing old papers up to 75%. The felt papers are unsized, beaten very free, and run over a cylinder paper machine, pressed as lightly as possible, dried over regular drying rolls, very lightly calendered or not at all, and then slit into rolls from 32 to 110 in. in width. The Fourdrinier machine may be used, but the cylinder machine is most generally employed. Felt papers are run to a weight of 30 to 110 lb. on a basis of 12 × 12—480. Felt papers that are to be saturated are run to a certain per cent saturant; for example, *floor felts* are generally made to take up a weight of saturant equal to 125% to 135% of the weight of the felt. Felts for roofing usually run higher—from 140% to 165% saturant.

The **asbestos papers** are all asbestos or asbestos and some rag stock mixed. The *asbestos boards* are mixtures of asbestos and plaster of Paris or asbestos and cement, with suitable pigments added for coloring matter.

Sheathing papers of the red, blue, or gray rosin variety are nothing more than a hard-sized gray mill wrapper, one side colored as required. These papers are sold in rolls of 32-, 36-, or 48-in. widths and 500 sq. ft. per roll. The basis weight runs 125, 250, and 300 lb. per ream of 24 × 36—480. The new sheathing papers, introduced since 1925, are, primarily, fibrous mats made from waste wood, grasses, or other waste vegetable materials. These are defibered by combination chemical-

- Insulating Papers
  - Heat-Insulating Papers
    - Felt
      - Refrigerator lining
      - Floor felts
      - Roofing felts
      - Floor lining or deadening felts—plain or indented
    - Asbestos
      - Paperboards
    - Sheathing
      - Red, gray, or blue rosin sheathing
      - Paper-lined felted fibrous products
    - Wallboard
      - Pulpboard—solid or laminated
      - Plaster board—may be same as pulpboard
      - Gypsum board—single or double lined with paper
  - Electrical Insulating Papers
    - Not impregnated
      - Condenser paper
      - Cable wrapping
    - Impregnated or coated with
      - Shellac, varnish, paraffin, bakelite
        - Used for insulating electrical equipment
    - Chemically or mechanically treated
      - Vulcanized fiber—zinc chloride treatment
      - Vegetable parchment—sulphuric acid treatment
      - Viscolized fiber—caustic soda and carbon disulphide treatment
      - Mechanical parchment—by long mechanical hydration

mechanical processes, put into a thick spongy mat, and then put between two sheets of lightweight wrapping paper. Such a material has excellent insulating properties against heat, wind, and sound, and it adds a real value to any building, especially a dwelling.

Wallboard is a general term that applies to many thick, heavy boards, made solid or laminated, and made either of all fiber or of part fiber and part plaster of Paris. It is made in widths of 32 and 48 in., and in lengths of 4 to 18 ft. The thickness varies from $\frac{3}{16}$ in. to approximately 1 in. Wallboard may be made with a hard surface sizing, in which case, it is used as the interior trim in a room; or it may be made with a slack-sized surface and plastered over, in which case, it is correctly called *plaster board* or *plaster wallboard*. The *gypsum board* is a board made

up of a thin sheet of gypsum or plaster of Paris, with a gray wrapping paper on one or both sides; gypsum board is always covered with plaster, wallpaper, or paint. The sizes of plaster board are about the same as for wallboard, with a maximum length of 10 ft. in 32- and 48-in. widths.

The electrical insulating papers include the following: **Condenser paper,** a very lightweight sheet, used in making small electrical condensers.

Cable-wrapping paper, used for insulation and for spacers in a multi-wire cable. Made of rope stock or of rope and kraft pulp mixed. The basis weight is from 25 to 50 lb. per ream of 24 × 36—480, and the furnish is beaten to secure a slow stock of maximum tensile strength. The paper is made in several colors, is cut into strips of $\frac{3}{16}$ to $\frac{5}{8}$ in. wide, and is reeled into rolls of about 10 in. in diameter. This grade of cable-wrapping paper is made on a cylinder machine, in order to secure maximum tensile strength in machine direction. There is also a grade of cable-wrapping paper made entirely from kraft pulp in the usual kraft weights of 30, 40, and 50 lb. per ream of 24 × 36—480. This grade is cut into strips about $\frac{1}{2}$ in. wide, and is used to wrap wires in certain kinds of telephone cables where spacing is most important.

The *impregnated*, or *coated*, *papers* are usually made of kraft pulp as a base stock.

39. Jute Paper.—A strong wrapping paper, made of burlap or jute waste, and may contain some old rope stock; used for heavy wrappings and for hydrated lime and cement bags; may be made up of a duplex bag paper for flour bags or sacks. Some drawing papers are made from jute fiber, up to 75% to 80% jute and the remainder rags or sulphite.

MATERIALS: Jute fiber is obtained almost entirely from old jute bagging or burlap: rope is never made of jute fiber.

PREPARATION: The old burlap bagging is first 'opened up' in some form of a duster or thrasher, where the pieces are shaken out, and some dirt and dust are removed. The material is then very coarsely sorted, cut in regular rag cutters, given a light dusting in regular dusters, and fed into rotary boilers. Excellent results may be obtained with a 10- to 12-hr. cook at 25 to 30 lb. pressure, using 8% to 10% of lime; this means 8 to 10 lb. of

hydrated lime to each 100 lb. of dry jute. Mills sometimes use up to 20%, but this is an absolute waste. After cooking, the jute is washed, beaten to half-stuff, and bleached with 5% to 10% of chlorine. The best color is a medium to dark straw yellow. Jute stock is not a strong fiber, and care must be taken not to overcook, overbleach, or overbeat it. Jute stock will not hydrate, as will linen or manila fiber.

MAKING AND FINISHING: This is the same as in regular paper-making practice. Either cylinder or Fourdrinier machines may be used, and the sheet is well sized with rosin and alum. For bag papers, the paper is given a light or medium finish on the machine, and slit and wound into rolls of various widths.

Jute stock is also used in some of the lower grades of drawing papers, in which case, it is very hard sized, and cut short in the beater and Jordan; and, for best results, it is given a glue surface sizing on the paper machine. Basis weights for jute bag papers are the same as for wrapping papers; *viz.*, 50 lb. to 200 lb. for reams 24 × 36—480.

40. Kraft Bag Paper.—A wrapping paper made of sulphate pulp, and used in the manufacture of paper bags. So-called kraft bag papers may be made from sulphite pulp and colored to resemble a true kraft paper. Basis weights are those of regular kraft wrapping paper, 25 lb. to 150 lb. per ream of 24 × 36—480.

41. Kraft Papers.—A paper made wholly or principally of sulphate, or kraft, pulp. There are grades on the market called No. 2 and No. 3 kraft that may contain unbleached sulphite, and, in some cases, may contain groundwood pulp.

MATERIALS: The best grades are 100% sulphate, or kraft, pulp; lower grades may contain sulphite or groundwood pulps.

PREPARATION: The best grades of kraft paper require the use of Northern coniferous woods, especially spruce. The so-called Southern kraft papers are made largely from Southern pines; up to the present time, they do not quite equal the best Northern kraft papers made from spruce. This difference has been materially reduced, and studies now being made indicate that still further improvement will be effected.

The beating of kraft pulp is most important, and must be carried out in such a way as to 'slow up' the fiber without much

shortening. Many of the lower grades of kraft paper on the market are largely due to incorrect methods of beating.

MAKING AND FINISHING: The making of *kraft-paper bag* closely followed newsprint production in the development of wide high-speed paper machines. It must be carefully formed on the Fourdrinier, and be handled on presses, dryers, and calenders as is newsprint, to secure maximum production at minimum cost, since competition is very keen, and only the very modern mill close to its source of raw material may long exist. Kraft paper is sold in sheets and rolls on the basis of 20 to 150 lb. per ream of 24 × 36—480.

42. Ledger Paper.—This grade has some characteristics like bond papers, but is made in heavier weights, and is well sized to withstand erasures. The fibers are beaten shorter than for high-grade bonds, and the formation must be close and well formed. Used where durability is essential, as in account books, court records, bank statements, deeds, and other legal forms and documents: now made in several grades, of same general characteristics, as uses have become more general.

RAW MATERIALS: For some purposes, only rags are used; in other grades, down to 25% rags (thirds and blues) and 75% sulphite, to all sulphite. The rags are cooked with lime and soda ash, washed and bleached, and beaten from 6 to 10 hr., for best grades of all-rag ledgers. Sulphite is beaten light, or brushed, for 2 or 3 hr. Sulphite furnish is jordaned fairly hard; rag furnish, not too heavy, leaving stock fairly free and not too long; rag furnish tends to be slow. Hard sized with 2% rosin and 3% alum. Common shades are white, buff, blue, and pink.

MAKING AND FINISHING: Ledger is made on a Fourdrinier with 65- or 70-mesh wire, with plain wove or watermarking dandy roll. With 4 suction boxes, the vacuum will be about 6 in., though this varies between wide limits, depending on grade of paper, weight of sheet, and size of machine. Speed depends on weight of paper and stock condition: for part-rag furnish, about 125 f.p.m.; for all sulphite, about 250 f.p.m. for lighter weights. Machine may have 3 presses, or 2 presses and smoothing rolls. Better papers are tub sized with gum or glue, and machine finished, using 2 stacks for sulphite ledgers; better grades are supercalendered or plated. Wrapped in reams or half-reams,

and packed in cases. Basis weights, 20, 24, 28, 32, 36, 40, and 44 lb. usually, but in a few cases, 48, 52, and 60 lb., per ream of 17 × 22—500.

43. Linen or Linens.—A term much misused and much misunderstood. Three distinct meanings are known and recognized in the trade: (1) a writing paper having certain distinctive characteristics; (2) a surface finish having distinctive characteristics—also the name given to the material that produces this particular finish; (3) a raw material that is used to make into paper. The raw material from the flax plant, used to make linen, needs no explanation or description.

The surface finish referred to above is obtained by pressing a piece of linen cloth against a sheet of paper, and the weave of the linen cloth is reproduced on the paper surface. The cloth is called 'linens,' the finish or surface marks are called 'linen finish,' and the paper is sold to the trade as a writing paper called 'linens.'

There are on the market (though not now in general use) some lightweight writing papers (17 × 22—500, 11, 13, 16, and 20 lb.) that have watermarks of rather large design, in both laid and wove, and in white or cream color. These papers are called linen or linens, and were the writing papers that were in general use prior to the bond papers that we know now. The term was originally applied to a handmade paper on a laid mold, with a large, elaborate watermark; the color was a distinct cream shade, and the raw material was partly linen fiber. Later on, the making of a woven wire cloth resulted in the present 'wove linens'; and as bleaching progressed, we had the white or nearly white linens. Bond papers have almost entirely replaced linens, since linens belong to the age of the quill pen and the sand pot, while bond papers belong to the age of typewriters.

The making and finishing of linens are very much the same as for bond papers, but special care is given to securing a clear watermark.

44. Manila.—A name that formerly meant a strong wrapping and bag paper made of old manila rope or bagging. Some such paper is now made, but the term has come to refer to a yellow tinted paper made of unbleached sulphite pulp or of sulphite and

groundwood. (See Envelope, Wrapping, and Writing papers, Arts. **26, 74, 75.**)

The manila wrapping papers made of sulphite or sulphite and groundwood pulps replaced rope manila papers, as well as the old cheap straw wrapping papers; and now, with the introduction of the sulphate process using the Southern pines, we obtain a kraft wrapping paper that is very largely replacing the old wood manilas. The basis weights for all wrapping paper are 15 to over 200 lb. per ream of 24 × 36—480.

45. Manila Wrapping.—A term applied to a group of manila-colored wrapping papers, made of sulphite or a mixture of sulphite and groundwood pulps; used for various wrapping and printing purposes, and also for envelopes, filing folders, etc. (See under Manila, Art. **44.**)

46. Manila Writing Papers.—Also called *railroad manila* or *yellow railroad manila.*

MATERIALS: Unbleached sulphite and groundwood pulps. From 25% to 65% groundwood pulp.

PREPARATION: No beating, and not much jordaning; hard sized with rosin and alum; yellow or buff in color.

MAKING AND FINISHING: Usually made on a Fourdrinier. Must have close formation and a smooth writing surface suitable for pen and ink. Finished on the machine, and sold in regular writing-paper sizes. This grade of paper is a cheap writing, and it may also be used as a cheap paper for filing copies of letters.

47. Mimeograph (or Multigraph).—An unsized absorbent printing paper; used for duplicating by means of a mimeograph or multigraph machine. This paper may also be partly sized, so it will take a signature in ink.

RAW MATERIALS: Commonly, 50% bleached sulphite and 50% soda pulp or hardwood sulphite, but may contain rags or paper clippings.

PREPARATION: The stock must be free; beating is done quickly, the Jordan is set hard, and stock is put through quickly with plenty of water, except for dandy-roll-watermarked, higher grade papers. May be sized with 1% of rosin, loaded with 25% of clay, and tinted with blue for blue white, or with auramine for cream white.

Making and Finishing: Use Fourdrinier, 70-mesh wire, plain wove or plain laid dandy roll; usually, two suction boxes are enough; free stock requires only a light vacuum; speed, about 200 f.p.m.; light finish on machine calenders. The trade regularly uses two finishes—rough and smooth. The rough is a very light machine finish, and the smooth is about a medium machine finish. Weight basis is always 20 lb. per ream of 17 × 22—500.

48. Newsprint.—A printing paper developed for the printing of the daily newspaper; consists mostly of groundwood pulp, soft sized and machine finished; used for various printing purposes when permanency is not required, and in cheap tablets.

Materials: About 75% groundwood pulp and 25% unbleached sulphite; the proportion depends on the quality of the pulp and the speed of the machine.

Preparation: The pulp is measured and mixed in slush form; if dry pulp be used, it is generally shredded and mixed with water, or added to the other slush. Broke from paper machines is re-conditioned by beating and rather stiff jordaning; in some mills, all stock is passed through the jordan. No sizing is required, but some alum—less than 2%—is used to fix the color. The prepared stock will have a freeness of about 170 at 4%, or about 60 at 3%. The consistency at the headbox will be 0.4% to 0.6%. White news is tinted with methylene blue and violet, news blue, etc.

Making and Finishing: Newsprint is made on a Fourdrinier machine, with 65-mesh wire, 7 or more suction boxes, suction couch roll, usually no dandy roll; many machines have a suction press roll. Speeds at present are 800 to 1200 f.p.m.; vacuum, 7 to 15 in. on suction rolls, and 3 in. to 7 in. on the boxes. There are three presses, and the steam pressure varies from atmospheric, or less, to 1 lb., or more. The paper is given a hard, but not high, finish on the machine, and is slit and rewound in rolls of the width ordered. A comparatively small amount of newsprint is cut into sheets and packed in bundles. Basis weight is 32 lb. per ream of 24 × 36—500.

49. No. 2 Kraft.—A kraft paper of second grade, because made of second-grade pulp, poor papermaking, or because of

admixture of groundwood pulp. (See Kraft Papers, Art. **41**, for details.)

50. Offset Paper.—A printing paper, specially sized for offset printing. The finish, non-curling, and absorptive qualities are of great importance; should be free from surface lint and fuzz, and is generally slightly antique finish. (See Offset Book, Art. **9.**)

51. Onion Skin.—A durable, lightweight writing paper, thin, and usually quite transparent; used largely for making duplicate copies of typewriting, for interleaving counter order books, and for permanent records when small bulk is desired.

RAW MATERIALS: The best grades contain 100% new rags; other grades, up to 75% sulphite.

PREPARATION: Beaten 8 to 18 hr., depending on raw materials used, until slow and greasy, keeping fibers long; no loading is used; sized with 2% rosin and 2% alum, and tub sized with starch or glue. Tinted for white, or colored for buff, pink, primrose, canary, etc.

MAKING AND FINISHING: Made on Fourdrinier, with 70-mesh wire, plain or watermarking dandy, 3 suction boxes at 5 in. vacuum, suction couch at 10 in. vacuum, and 3 presses; speed, 75 to 150 f.p.m. Usually given a high finish on supercalenders or plater, hand sorted, and wrapped in reams. Basis weights, 7, 8, 9, 11, and 13 lb. per ream of 17 × 22—500.

52. Paraffin Paper.—A sized or unsized paper, passed through a bath of melted paraffin or wax; lightweight paper generally used; employed for sanitary wrappers and covers. Basis weights, 15 to 60 lb. per ream of 24 × 36—480.

53. Parchment Paper.—(*a*) A term used to designate a kind of paper resembling the skin of a goat, sheep, or other animal; made by treating a waterleaf rag sheet with sulphuric acid. This kind of paper is correctly called *genuine vegetable parchment paper.* (*b*) A very high-grade heavyweight bond paper, made in imitation of genuine sheepskin parchment, to be used as a substitute therefor. Basis weights for vegetable parchment paper are 30, 40, 50, and 60 lb. per ream of 24 × 36—500; and for *parchment deed*, 24, 28, 32, 36, and 40 lb. per ream of 17 × 22—500.

54. Poster Paper.—A colored newsprint or low-price book paper; used for handbills, on billboards, etc. Slightly sized; must be strong enough to stand pasting and handling.

RAW MATERIALS: From 50% to 70% groundwood pulp, remainder is unbleached sulphite pulp.

PREPARATION: Mixed in beater, sized with 1% rosin and 2% alum, colored with dyes that should be fairly fast to light. Jordan very light, if at all.

MAKING AND FINISHING: Fourdrinier machine, ordinary conditions; speed, about 350 f.p.m.; weight runs heavier than for news; fairly high finish. Put up in reams—flat, folded, and lapped, and also in rolls. Basis weights, 35 to 45 lb. per ream of 24 × 36—500.

Railroad Writings.—See under Manila Writing Paper, Art. **46.**

55. Roofing Papers.—A general term applied to any material used in waterproofing upper decks of buildings. There are several varieties, as: (*a*) *Prepared roofing*—saturated felts, saturated and coated with asphaltum, plain or crushed slate, or other grit, imbedded in asphalt-coated surface. (*b*) *Built-up roofing*—saturated felts, saturated but not coated with asphaltum; put on roofing decks in plies or layers, and coated or built up at the time of application. (*c*) *Roofing shingles*—saturated felts, saturated and coated with asphaltum, crushed slate, shell, or gravel, imbedded into the surface while hot, and then cut into various styles of shingles.

Roofing papers are made from roofing felts or dry felts that have been impregnated with tars or asphalts. The *roofing*, or *dry*, *felt* is a soft, very porous paper, made largely of old cotton and woolen rags and some old-paper stock. The quality of the dry felt is dependent on the quality of the rags used, and the amount. The rags are prepared or beaten as quickly as possible, since the freest possible sheet is most essential. Dry felts can be made on a Fourdrinier machine, but are generally made on a cylinder machine. No sizing or loading is used. The basis weight is the weight in pounds of 480 sq. ft.; or it is the weight of a ream 12 × 12—480, and runs from 15 to 110 lb.

56. Rope Manila.—A wrapping paper of manila color, made principally of rope stock, the remainder being free from mechanical pulp. This paper has very great strength and pliability, and is used largely for cement bags, flour sacks, special envelopes, and other papers where strength is essential.

Manila-rope stock is first cut in a very heavy rag cutter, and is then cooked in rotary boilers for 10 to 12 hr. at 25 to 30 lb. steam pressure, using 10% of lime. Some soda ash, up to 2% or 3%, may be used if the rope is very dirty from oils and grease. The cooked stuff is washed and beaten to half-stuff, and only lightly bleached, if at all, since rope stock never bleaches lighter than a dark straw color. The beating of this stock must be done with as much care as the beating of linen for a bond sheet, since the maximum of strength must be secured. Carefully beaten manila rope will give a paper equal in strength to linen, if the rope stock is of first quality.

The manila-rope papers are well sized with rosin and alum, and may be made on either a cylinder or a Fourdrinier machine. The finished paper is put up both in sheets and rolls, and is made on the regular wrapping-paper basis of weight; *viz.*, 30 to 300 lb. per ream of 24 × 36—480.

57. Rotogravure Paper.—A highly finished, uncoated printing paper, made of bleached mechanical and chemical pulps; used for printing by the rotogravure process. The furnish is about 50% bleached groundwood and 50% bleached sulphite. The groundwood is specially prepared, and it must be free from shives or large woody particles. The furnish is carefully beaten, lightly sized, and run over modern, high-speed Fourdrinier machines. The machine finish is high, and the final finish is a high supercalender finish. The paper is usually sold in rolls, and is used for printing by the rotogravure process, which includes much of the fine photographic reproductions found in Sunday newspaper supplements and in magazine picture publications.

58. Saturating Felts.—The term saturating felt is applied to those heavy papers which are used as a vehicle to carry and hold various tars, asphaltum, or other waterproofing compounds; these are sometimes designated as *waterproofing felts*. (See details under Roofing Papers, Art. **55.**)

59. Safety Papers.—A paper treated to make visible any attempt to erase or to change anything that has been written or printed on its face. Such a paper is used for bank checks, tickets, postal money orders, or other papers having a negotiable value. Safety papers are made by the addition of chemicals in the beater, by surface treatment in certain chemical baths, or

by the printing of some all-over design on the surface of the paper, using an ink, or inks, sensitive to water, soaps, chemicals, bleach, and mechanical erasure. Usually made of part rag or all sulphite, hard sized for pen and ink, and printed with a surface design using a fugitive ink.

60. Sensitizing Paper.—The base paper is treated with a sensitizing solution to make the surface reactive to light or chemicals; refers principally to paper used in manufacturing blueprint, photostat, photographic, etc., papers. Paper for photographs, as compared with the commercial paper described herein, is heavier, made of finer, shorter stock, and is practically, if not quite, free from chemicals. The sensitizing of photographic paper is a combination of a coating and a surface impregnation.

RAW MATERIALS: Best grades are made of 100% new rags; other grades contain strong bleached sulphite, with new or old rags in varying proportions.

MAKING AND FINISHING: Made on Fourdrinier machine at speeds depending on the rag content and character of product required. Usually tub sized with glue or gelatine of about 3° to 4° Be. at 125°F., to which alum or a very small amount of formaldehyde may be added. More than 1 qt. of formaldehyde to 300 gal. of glue will make a surface too hard for the sensitizing solution. Starch is also used. Paper-machine calendered, slit and rewound to width, supercalendered, and shipped in rolls.

61. Sheathing.—A term applied to a paper made to be used as a heat-insulating material and as wind stops in houses. This group of papers is used between rough boards and the finish in the outside walls of frame buildings, for protection against wind and dust. It is a heavy grade of wrapping paper, like gray mill wrapper, made of old papers, screenings, and some low-grade, unbleached chemical pulps. It may be colored red or blue, and should be hard sized with rosin and alum; it is sold in 36- and 48-in. rolls.

62. Soap Wrapper (Alkali-Proof).—Paper used for wrapping individual cakes or bars of soap. Must be sized, to prevent moisture from affecting the soap, and colored with dyes that will not be discolored by any alkali that may be in the soap;

must also be free from any groundwood pulp. Inside wrappers are frequently not colored.

MATERIALS: Bleached sulphite used for the better grades; good quality strong, unbleached sulphite used for cheap, semi-greaseproof; alkali-proof paper should be free from groundwood.

PREPARATION: Stock for the better grades is beaten as for sulphite bond, or good sulphite wrapping, 1 to 4 hr., with good brushing for strength; sized with 0.5% to 1% rosin, and alum to give a pH of about 4.5. Bleached stock is not usually colored; but where required, an alkali-proof color, such as indanthrene blue, is used. For cheaper grades, the stock is well beaten, to give a semi-greaseproof sheet, and well jordaned; but the fiber must not be cut too short.

MAKING AND FINISHING: Made on Fourdrinier machine at 300 to 600 f.p.m.; the sheet should have a well-closed and even formation. Consistency at flow-box is 0.3% to 0.5%, depending on weight of the paper and speed of the machine. Three presses are generally used, with or without smoothing rolls. The paper is well calendered on the machine, and is rewound into shipping rolls. Paper may be tested by wrapping it about a cake of laundry soap and exposing it for 1 to 3 weeks in a moisture-saturated atmosphere, in a desiccator; no marked reddening or brown coloration should appear on the paper.

63. Stereotyping Tissue.—A strong tissue, made of cotton and linen rags, and used as a facing in the production of matrix mats for printing purposes. (For further details, see under Bible Paper, Art. **6**, and Cigarette Tissue, Art. **18.**)

64. Straw Wrapping.—A coarse wrapping paper, made of wheat or rye straw; used by packers and butchers for wrapping meat, and for lining wagons in which meat is delivered. This grade of paper has been largely superseded by the wood manilas, and, subsequently, by the kraft papers. The straw was cut, dusted, and cooked in rotary boilers, using 10% of lime and 30 lb. steam pressure for 10 hr.; then washed and beaten, and run over a cylinder paper machine.

65. Tissue Paper.—A general term indicating a class of papers made in weights lighter than 10 to 12 lb. per ream of 24 × 36—480. Generally made on a Yankee or Harper machine, or on a

single-cylinder machine; glazed or unglazed; of rag, sulphite, or rope; used for a large variety of purposes.

Anti-tarnish tissue, also called *gross bleached,* is a tissue paper free from acid or sulphur compounds, so that when used as a wrapping for silverware or steel kitchen ware, it will not cause discoloration of the silver or rusting of the steel. It is made from rag or bleached sulphite pulps that have been carefully bleached and washed; it is made on a single-cylinder machine.

66. Tracing Paper.—A thin, transparent paper, used for tracing drawings or plans. Blueprints can be made from drawings made on this paper in black ink, or even pencil, and also of typewriting, especially if carbon paper is used to duplicate the wording on the back. Tracing paper may also be coated with oils, to make it more transparent.

RAW MATERIALS: High-grade, strong, bleached sulphite pulp and rags are used, and the furnish is beaten to give a slow, transparent sheet.

PREPARATION: The stock is beaten 5 or 6 hr. and well hydrated, but not allowed to heat up; a well-jordaned, slow stock (slippery) is wanted; should be well sized, using 2% to 3% rosin; tint to white with red or blue dye.

MAKING AND FINISHING: Fourdrinier speed should not exceed 175 to 200 f.p.m. Adjust water in stock and pond behind slices to avoid ripples or waves; vacuum on 4 suction boxes is about 6 in., and is 14 in. on suction roll. No tub sizing is necessary, and smoothing rolls are not required. A high finish is not wanted; calender lightly, and rewind in hard rolls of the width and yardage desired. Wrap carefully, and pack in cases: sheets are not much used. Tracing paper must have enough 'tooth' to take pencil and pen, and not allow ink to spread.

67. Tympan Paper.—A paper used by printers for backing around the platen cylinder of the printing process; it is always finished in rolls, in widths equal to the standard widths of the printing press, and is generally a stiff manila-colored wrapping, oiled or uncoated; made of jute, manila, and sulphite, well sized, and of high machine finish. Must be free from hard spots, since hard spots are liable to injure the face of the type.

68. Vulcanized Fiber.—A waterleaf paper made from old rags is unwound through a treating solution of zinc chloride,

where gelatinization takes place; then rewound over and around heated cylinders, one ply on the next, all combining into a homogeneous sheet, the number of plies so wound on the cylinder determining the final thickness of the vulcanized fiber. The sheet is then cut across the cylinder and taken off onto tables. It is next immersed in several baths of diminishing concentration of zinc chloride until it is thoroughly purged in fresh-water baths. This purging process takes from 12 hours to 6 months, according to the thickness of the sheet. It is then hung in dry rooms until it is thoroughly dry, pressed flat in hydraulic presses, and calendered for a finished surface. The hardness of the paper changes inversely the hardness of the resulting fiber; soft papers take the more intense treatment, and therefore shrink into harder fiber products. The larger companies also simultaneously combine several plies after passing through the treating baths on continuous machines; this process is applicable only for the thinner weights. After passing through the baths of diminishing concentration and, finally, in pure water, the continuous sheet is carried over a cylinder paper dryer, then calendered, and cut into sheets or made into rolls, to be subsequently cut into strips or coils.

The principal uses for vulcanized fiber are electrical insulation, trunk covering and binding, sample cases and special hand luggage, and for electrical or mechanical assemblies.

69. Vulcanizing Paper.—Paper for the manufacturing of vulcanized fiber requires freeness and strength of fiber. It is a 'waterleaf' sheet, such as is also used for vegetable parchment, but is usually of a heavier weight and is in a great variety of colors. (Treated as described above, Art. **68.**)

Raw Materials: New rags and old rags chiefly used; colored rag fiber is bleached.

Preparation: Rags are well cooked; beating is with sharp tackle in 2 to 4 hr.; rags are sometimes beaten separately, sometimes with pulp; loading should not be used; no sizing is used, since free stock and absorbent paper is required to take up treating solutions rapidly; Jordan settings vary from light brush to hard. Pigment colors are usually employed, occasionally with addition of some dyestuff, the common shades being olive, russet, red, browns, and black.

Making and Finishing: Made on Fourdrinier, with 60- to 65-mesh wire; 3 or 4 suction boxes, with 4 to 8 in. vacuum; may use plain wove dandy; speed varies from 90 to 300 f.p.m., and paper from 25 lb. for hard to 90 lb. for soft, free qualities. Paper is put through the machine calenders, but finish is not required; slit and rewound for vulcanizing machine. Common width is 60 in. for roll of 800 to 1200 lb.

70. Waterleaf Paper.—An unsized paper, used for conversion by chemical processes into vegetable parchment, vulcanized fiber, etc. The term 'waterleaf' is sometimes used in connection with filter paper and commercial blottings. Old cotton rags give best results, though some bleached sulphite pulp may be used in the lower grades.

71. Waxing Paper.—Paper made for waxing purposes comes in a wide range of weights—from lightweight tissues as low as 7 lb. per ream of 24 × 36—480 to heavy folding boxboard that is used for waxed cartons. Those grades known to the trade in general as 'waxings' cover a range of weights from 7 lb. to 50 lb. per ream of 24 × 36—480; they may be roughly divided into florist and twisting tissues, bread wrappers, and waxing specialties.

Florist and Twisting Tissues

Materials: Bleached or unbleached strong sulphite, sometimes sulphate, pulp. Pulp should be well beaten for strength, and kept as 'long' as possible for strength and resistance to tear.

Preparation: These tissues are usually made on cylinder machines that are particularly adapted to making twisting tissues. Used on automatic candy-wrapping machines, and strength to withstand twisting is essential. Machines run at speeds of 200 to 350 f.p.m.; should go to machine calenders containing as much moisture as practicable, usually 7% to 8%, and should have a high, uniform finish, free from pinholes. It is very important that the weight across the machine be kept within very narrow limits, to avoid uneven waxing on the waxing machine.

Packing and Shipping: Shipped in rolls of suitable width for printing presses and waxing machines.

Bread Wrappers

Bread wrappers are of two general types, known as self-sealing and dry waxing. Both types range in weight from 19 lb. to 25 lb. per ream of 24 × 36—480.

Self-sealing papers carry a high machine finish and, in some cases, have even been supercalendered; they must have a reasonably close formation, a long fiber, and good strength. High surface finish prevents too much penetration of wax in the wax bath; and before the hot wax can penetrate deeply, it is chilled by passing the paper over rolls that have been chilled by refrigerated brine. The papers thus produced are generally used in automatic wrapping machines; and when the fold has been made, the package passes between heated plates, which fuse the wax on the folds. The package is then carried along between felts, which hold the fold in position until the melted wax has cooled.

Dry waxed papers carry a low finish, which aids penetration of the hot wax. After the paper receives the hot wax, it is passed over heated rolls, which cause the wax to be absorbed largely into the interior of the sheet. These papers are also used in automatic wrapping machines, but some external sealing agent—usually hot wax—is used to seal the package.

MATERIALS: Strong bleached or semi-bleached pulp is used for both types; it should be well beaten for strength, and kept 'long' for folding qualities. Opaque pigments are used for better color in print papers. Paper for self-sealing may be beaten somewhat slower than for dry waxing; but it should not be too highly hydrated, as it tends to become brittle in the subsequent waxing process. Many mills use rosin size in preparing waxing furnishes, but size has very little, if any, effect in resisting penetration of wax, which seems chiefly to be regulated by the surface finish and degree of hydration. Colors should be chosen with regard to the color effect *after* the waxing process, since the degree of transparency of the finished sheet greatly affects the color.

PREPARATION: Bread wrappers are made on Fourdrinier or Yankee machines, at speeds of 300 to 1000 f.p.m. Self-sealing papers should carry 7% to 9% moisture, and have a high machine finish—one or two stacks of calenders. Dry waxing papers should have a very low, even finish, and should carry 6% to 8%

moisture. Both types must have the weight controlled within very narrow limits across the machine.

PACKING AND SHIPPING: Shipped in rolls of widths to suit printing presses and waxing machines; all breaks should be very carefully spliced and flagged, and the rolls well protected for shipment.

Specialties

Special waxing papers, of the self-sealing or dry-waxing types, are made and furnished like bread wrappers; they are, in general used on automatic wrapping machines, but are usually heavier than bread wrappers. They are largely used for the wrapping of cartons containing food or material in which it is desired to maintain a constant moisture content.

72. Wedding Bristol.—A term applied to a group of high-grade bristols, made by pasting together two or more sheets of finished or unfinished paper, of rag content, in different thicknesses or plies; plated to give various finishes; used for cards, announcements, etc.

Basis weights per ream of 22½ × 28½—500 are: 2-ply, 120 lb.; 3-ply, 180 lb.; 4-ply, 240 lb.

73. Weddings.—Superfine writing papers of medium to heavy substance, slightly modified for better folding; exceeding delicacy of texture; finish usually of vellum or kid style, *i.e.*, smooth to the touch, but lacking in sheen or glare; may carry other finishes, as high plate or linen; particularly adapted to steel-engraved wedding announcements; frequently used for social correspondence. Basis weights, 60, 70, 80, 90, 100, 120, and 160 lb. per ream of 21 × 33—500.

74. Wrapping Paper.—A broad classification, including many kinds of raw material, manufacture, and quality; used generally for wrapping purposes, and of practically the same qualities in some grades for making bags and envelopes. Should be strong, pliable, and have good folding qualities.

RAW MATERIALS: Groundwood pulp, sulphite, sulphate, straw, rope, jute, old rags, and waste papers are all used to make wrappings. Anti-tarnish papers require that the pulp and other materials be free from sulphur. A common manila wrapping of good quality contains 25% of groundwood and 75% of sulphite.

Preparation: This stock is beaten 3 hr., sized with 3 % rosin and alum, colored with auramine O, and jordaned fairly hard.

Making and Finishing: Made on Fourdrinier (wrappings are also made on cylinder and Yankee machines, the latter producing M. G. papers) with 65-mesh wire, 3 suction boxes, suction couch (with 12 in. vacuum), 3 presses, 2 8-roll calenders. Rewound and packed in rolls, or cut in sheets and packed in reams.

Medium Wrapping

Another furnish is 70% bleached sulphite and 30% soda pulp, with a loading of 8% to 10% talc, and 2½% rosin and alum size. This is beaten and jordaned fairly hard, to give a fine free stock. The stock is thin at the headbox, a watermarking or plain dandy is used, and light suction—4½ in. on boxes and 9 in. on suction couch.

Manila Wrapping

This sheet may be made of various mixtures of sulphite and soda pulps, or with some groundwood for cheaper grades; the more soda pulp used the less is the beating. About 10% talc is used, 2½% rosin and alum size, and a small range of colors, as blue, pink, canary, and golden rod; jordaned fairly hard, to get a rather slow stock. The stock is thin (0.5%) at the headbox; not tub sized; given high machine finish, using 2 stacks if they are available. Wrapped in 500-sheet reams and packed in cases; or packed in lined cases with markers between reams.

Used for tablets, filing sheets, and printed forms where writing ink is used.

75. Writing Paper.—This class comes in many qualities, colors, and finishes, from manila writing to de luxe stationery. It is required to have a good writing surface. Stationery papers must be rather soft and bulky, with pleasing colors and attractive finish. Papers made as writing papers are also used for booklets, statements, advertising, and circulars. Some characteristics overlap on bonds. A few typical grades will be described.

Stationery Paper

Raw Materials: Higher grades contain some rag, such as hosiery; a typical furnish for stationery is 75% sulphite, 15% soda, 10% soft rags.

PREPARATION: Beaten $2\frac{1}{2}$ hr.; sized with $2\frac{1}{2}$ % rosin and alum; loaded with 12% talc; common colors are blue, azure, fawn, cherry, canary, pink, green, amber, salmon, mauve, gray.. Jordan fairly hard.

MAKING AND FINISHING: Can be made on Fourdrinier, with 65-mesh wire, 4 suction boxes (8 in. vacuum), suction couch (14 in. vacuum), and plain wove or watermarking dandy; speed, 200 f.p.m. for a 40-lb. sheet per ream of 17 × 22—1000; tub sized with Hercules gum at 5° Be. The sheet is given a smooth machine finish, and then cut and plated, or finished on a continuous plater, cut, and trimmed. The paper is wrapped in 500-sheet reams and packed in cases.

Laid Writing

RAW MATERIALS: A furnish for this grade may be about—50% sulphite pulp, 20% hard shavings, 20% soft shavings, 10% soda fiber.

PREPARATION: The stock is brushed in the beater for 3 hr.; sized with $2\frac{1}{2}$% rosin and alum; 2% starch, 2% sodium silicate; loaded with 8% filler, such as talc; colored various shades, or tinted for white; brushed not too hard in the Jordan.

MAKING AND FINISHING: A 70-mesh wire may be used, since stock is rather short and free; not over 3 suction boxes (7 in. vacuum) required; consistency, about 0.75% at headbox; use laid dandy, with or without other watermark; smoothing rolls may be used; only light machine finish is given, and paper is supercalendered; it is not tub sized. Wrapped in $\frac{1}{2}$ ream and 1 ream, and cased.

76. Yoshino Paper.—This is the thinnest of all Japanese papers. It is made from the koso plant, which, like mitsumata, belongs to the mulberry family. The production of these plants is decreasing, while the use of wood pulp in Japan is increasing. Extraordinary care and skill are required to produce yoshino paper, which is used in Japan for lanterns, glass pasting, etc.; the thicker grades are used for napkins, and for toilet and wrapping paper.

PART 2—BOARDS

77. Binder's Board.—A stiff, hard board, used principally for book covers.

Raw Materials: All low-grade mixed papers generally used; rags not much used, since low-grade rags are too soft and flexible.

Preparation: Waste papers are sorted and cleared of strings, and are beaten from ½ hr. to 2 hr.; loading, sizing, and coloring are not used; stock is given a heavy brush in the Jordan and should be free.

Making and Finishing: This board is formed of plies from a single-cylinder wet machine, with stock at 0.5% to 0.75% consistency, using suction box under 10 to 12 in. vacuum. The stock is carried as thick as possible, but still giving the requisite compactness of the finished sheet; the thinner the film formed on the mold the more compact will be the finished sheet, other things being equal. When of the desired thickness, the sheet is stripped from the couch roll and dried in kilns. Finishing is done in heavy 2-roll calenders, usually set in pairs. It is cut to size, and is packed in 50-lb. bundles.

78. Bottle Cap (or **Cap Board**).—A good grade of pulpboard, about 0.040 in. thick, from which disks are punched for milk-bottle caps. It is subsequently waxed or paraffined; it must be stiff, strong, highly water resistant, and of very uniform thickness for use in automatic machines. A bright, natural color is desired.

Raw Materials: A common furnish for solid manila is 65% unbleached sulphite pulp and the remainder groundwood. Clay is frequently added; this gives a lighter color and compensates for the darkening when paraffining. Some grades contain small amounts of jute or rope stock; bottle-cap clippings are also used, replacing some of the groundwood. An all-bleached sulphite face is used for white-lined manila quality.

Preparation: The sulphite is brushed out for 1¼ hr., and the groundwood is given 15 min. The stock is very hard sized with rosin and alum, and is given a light brush in the Jordan, keeping it free.

Making and Finishing: Using a 6-cylinder machine, the speed would be about 50 f.p.m. on 40-point board; machines of 7 or 8 cylinders are better, allowing greater speed, more compact formation, and a stiffer sheet. Use as much suction[1] as possible without separation of the several plies,[1] and all the presses, including smoothing rolls, if the latter are available; use 2 or 3 stacks of calenders for good smooth finish. Shipped in rolls.

79. Boxboard.—Boxboard is made principally of waste paper, and is largely classified by the uses to which it is put; viz., (*a*) *folding boxes*, (*b*) *setup*, or *square, boxes*, (*c*) *containers*. Folding boxes may be vat-lined on one or both sides (*i.e.*, outer layers may differ from the center), according to the printing surface. (*Vat lining* means formed in one of the outer multicylinder machine vats, as contrasted with *mill lining* or *sheet lining*—pasting on a paper liner.) For bending quality, more sulphite or other long-fibered stock is added to the layer on the outer side of the board. Setup boxes are generally made of chipboard; sometimes a pasted sheet, news or glazed lined, on one or both sides. One lining may be applied before the box is made, the other being pasted on afterward. Container board has an especially strong sheet known as *test liner* (0.016 to 0.020 in. thick, and bursting strength 85 to 135 lb. per sq. in.), containing considerable kraft pulp and high-grade waste papers, pasted on either side of the filler. The paste is sodium silicate. The filler may be a sheet of corrugated 0.009-in. straw paper or kraft-paper stock combination. Test liner is also lighter weight all-kraft from either a cylinder or a Fourdrinier machine.

Besides the corrugated type, there is also the solid type, composed of heavy chipboard, lined both sides with test liner.

The different grades shade into each other, and carry trade names that have only a general significance. All orders are made to sample, except for weight, caliper, and strength, which must

[1] The *suction* here referred to is not the suction on the suction boxes (vacuum), but the difference in stock levels outside and inside the mold, called 'suction' by machine tenders. "Use as much suction as possible without separation of the plies," means to carry as thin a web on the cylinder as possible (by thinner vat stock and higher difference in levels), in order to give compactness of formation, and that the webs on the several cylinder molds, and the suctions on each, must be equalized. If one web is thicker than the other, the thicker web will not allow passage of water through it as fast as will the thinner web; this will cause 'blows,' or ply separation.

be specified. Similarly, the waste papers from which the boards are made are graded by the packers. Those used in board filler range from No. 1 print manilas, old kraft paper, office waste, and waste from paper-goods manufacturers, overissue news, etc., through No. 1 bundled news, baled news, and various grades of mixed papers, to dump stock. Box-shop waste also varies considerably with the care exercised in keeping out foreign material. Waste of better grades of paper is used as liner material; for example, the waste in threading newspaper presses, ends of rolls, etc., called *blank news;* envelope cuttings of different grades, including kraft; and book trimmings, known as *shavings.* The liners that are pasted on are practically a book-paper grade, and may be coated over side.

PREPARATION: Since most mills must draw their raw-material supply from the waste papers of a considerable area, it is economically necessary that these be sorted near the point of collection and baled for shipment. Bales are broken and papers repulped in beaters with warm water, to assist in breaking up the bundles of fibers. Since most of the stock has already once been beaten, it requires little treatment beyond repulping; hence, filler stock is prepared in beaters or large breaker beaters, fitted with continuous extractors. Hot water is necessary for rapid defibering. Stock extracted from breaker beaters is thinned with water to 0.5% to 1.0% consistency, passed over rifflers equipped with skimmers, where much of the refuse is removed, then thickened by deckers to chest consistency. Extracted stock usually goes to secondary beaters, where size, alum, etc., are added, though in some cases, it goes directly to the Jordan, the size and alum being added continuously in solution. Vacuum drum filters are being used in place of regular deckers; they act both as thickeners and as highly efficient save-alls, white water being used for dilution in the rifflers.

Liner stock is furnished direct to beaters, preferably of the fast-circulating type, and beaten from $\frac{3}{4}$ hr. to 2 hr. The longer beating time reduces fuzz, a decided detriment in printing. The Jordan is set fairly hard on filler stock, to eliminate lumps, specks, undefibered paper, etc. Liner stock, especially if well beaten, requires less jordaning, as it is essential to retain the bending qualities of the long stock used. In general, the thinner the sheet the more jordaning that is necessary. The main requirements for

liner stock are freeness, short enough to close easily and avoid a wild, cloudy liner.

Screens are usually of the flat-plate type, though cylinder types are being successfully used. Width of cut ranges from 0.011 to 0.020 in. on better grades, and up to 0.040 to 0.050 in. on coarse chipboard. Multicylinder machines with 5 to 8 vats are used.

MAKING AND FINISHING: The arrangement of vat, cylinder mold, baffles, and flow of stock, is a matter for considerable experiment. Present opinion seems to be that, for high speed, the vat should have a comparatively narrow space conforming to the mold, and the baffling should be reduced to the minimum that will insure an equal distribution of stock across the face of the mold. Vats having a narrow space conforming to the mold give more compact formation than those having larger clearances, as 5 in. to 7 in. It also seems that in order to get satisfactory formation, the consistency must be kept low; that is, if with 0.4% consistency, good formation can be obtained at 120 f.p.m., then to get 200 f.p.m., the size of the fan pump must be increased so that the consistency in the vat will still be 0.4%. As a rule, practice in the west differs from that in the east, in that the market in the west is satisfied with a somewhat poorer finish, and the machines there are therefore run at higher speeds. Three calender stacks are commonly used, the first serving for a water finish. Boxboards are shipped in rolls.

Building Board.—See Wallboard, Art. **95**.

80. Card Middles.—A stiff, cheap base that is lined or coated, and used largely for advertising signs, show cards, calender backs, etc.; also used as a filler in making cardboard. A close, dense formation, one that gives a very even liner surface, is important for obtaining good printing results.

RAW MATERIALS: Various grades of news, especially overissues, and groundwood pulp are used for the filler, with soft white shavings for liners. De-inked news is sometimes used in fillers, and de-inked book stock in liners. Typical furnishes are:

No. 2 Card Middles—For top and bottom liners: all overissue news; 3% rosin size and 4% alum. For fillers: all clean news; 3% rosin size and 4% alum (extra alum for stiffness).

No. 1 *Card Middles*—For top and bottom liners: 50% white news blanks, 50% clean manila shavings; 2.5% rosin size and 4% alum. For fillers: all clean manila shavings; 2% rosin size and 3% alum.

PREPARATION: The stock is sorted, if necessary. Some mills cook the waste papers, in which case, they are washed and not beaten, but are jordaned fairly hard, to get a slow, short-fibered stock; otherwise, the news is beaten 1 hr. to 1½ hr., and the shavings, 3 hr. to 5 hr. Liner stock is sized with rosin, sodium silicate, and alum. The machine is the usual type of boxboard cylinder machine, generally equipped with at least 6 cylinders and 4 main presses. This grade of board must be run very slowly, with light pressing, to insure smooth, even finish and freedom from felt marks. Smoothing rolls are desirable but are not always used. Drying is generally done at a fairly high pressure, as this is believed to increase the stiffness of the finished product. At least two stacks of calenders are always used, with water being applied near the top of the first stack. The board is wound in rolls for the coating mill.

This grade of paper is almost always coated, supercalendered, cut, and hand sorted. Case packing of the finished product was general practice until a few years ago, when carton packing was introduced with considerable success.

81. Chipboard.—A term referring to a variety of cheap board made on a multicylinder machine from mixed papers; may be combination (filled) or solid. (*a*) *Combination chipboard* is a board having a chip base or filler, vat lined on one or both sides with a higher grade of stock, and possessing a smoother and better appearing surface. News, groundwood, blank news, etc., are used for vat lining. It is used for setup boxes, cartons, solid fiber container board (as center), poster board, wallboard (laminated), for corrugated packing paper, and for wrapping. Bending qualities not required.

RAW MATERIALS: The raw material varies according to stocks on hand and market prices. Basic material—No. 1 mixed papers; frequently dump stock, dirty news, wallpaper waste, sorting out-throws, box cuttings or box chip, wrappings, etc., used with mixed papers. To free up stock on heavy weights (to allow faster operation without 'blowing'), free stocks, such

as strawboard cuttings, corrugated box cuttings, groundwood screenings, sulphite screenings, etc., are added; especially necessary when running thick boards on 4 or 5 molds.

PREPARATION: Stock may or may not be sorted by dealers in old papers, but sorted stock is preferable. The breaker beater removes strings and rags, and allows much heavy junk to settle out. Fine refuse is removed in rifflers preceding deckers; deckered stock to secondary beaters. Practically no beating is done, beaters being used for addition of special stocks (as sulphite for bending orders) and any size or loading necessary. Size not generally used, though 0.5% to 3% may be used on special orders. Loading and stiffening agents, as sodium silicate, are occasionally used. Well jordaned—harder on lighter weights and less on heavy weights or on poor grades. A rather free stock is wanted. One or both liners may be colored if required, or may be calender colored. Power consumption—beating (breaker beater plus beater), 15 to 20 hp. per 1000 lb.; jordaning, 30 to 60 hp.-hr. per 1000 lb. Freeness of No. 1 mixed papers before jordaning, 200–300 Green. Stock should not be held in chests too long.

MAKING AND FINISHING: Stock is fed at 0.3% to 0.5% consistency to (usually) 5- to 8-cylinder machine. Speed depends on number of molds, suction boxes, dryers, weight of sheet, etc., and is from 70 to 300 f.p.m. Flat screens with 0.022- to 0.050-in. slots are generally used, since the stock is then cleaned better. A large-production machine will have 7 to 8 molds, with 40- or 50-mesh facing, 12- or 14-mesh backing wire, 2 suction boxes on bottom felt, suction, or extractor, roll back of last mold, 2 to 3 wringer rolls, 7 to 8 baby presses, 3 main presses, possibly including suction press, suction box or felt cleaner on second-press felt. Smoothing press is desirable, but cannot generally be used without blows. The dryers are divided into 3 to 4 sections, and steam pressures are carried up to 40 lb.—or to the safety limit—on heavy board, especially the last sections. Drying steam per pound of board, 3.0 to 3.5 lb.

Calendering depends on the finish ordered. No. 1 finish (thick to number), 2 to 4 nips, no water, little or no weights. Nos. 2 and 3 finishes, more nips and weight; No. 3 finish, with water boxes but without steam rolls; No. 4 finish, the highest (thin to number), would use the full 3 stacks (6 to 8 rolls each); first stack with 4 water boxes (2 on either side of sheet), second

stack dry, third stack dry, but with 2 rolls bored for steam heating. Nos. 3 and 4 finishes use heavily weighted stacks; the first stack is called the water or breaker stack; the other two, finishing stacks. Calender colors may be applied in water boxes; also, special surfacing preparations.

The standard bundle for sheets is 50 lb., the *number* being the number of sheets required for 50 lb., and depending on thickness and finish. Bundles of 200 lb. are also made; and the boards are also shipped in rolls. Wound on drum reels, then cut by slitters, and duplex or triplex cutter, to sheets; or are slit to width and rewound as rolls on a 2- or 3-shaft upright winder, or on Cameron, Langston, Moore and White, or similar winder. Frequently wound as jumbo rolls. Sheet stock is run direct from third stack to slitter and cutter.

82. Combination Board.—A term applied to any board that is made of two or more different grades, the board being made in one operation. There are a large number of such boards, with innumerable combinations of stocks.

MAKING AND FINISHING: The board is made on a board machine of the multicylinder type; it must have 2 cylinders for a two-stock board (with liner and back), and 3 cylinders where three stocks are used simultaneously (forming a filler and top and bottom liners). For small calipers (thin boards) up to 0.020 in., 2 or 5 cylinders are suitable; but for calipers up to 0.050 in. (which cover most demands), a 6- to 8-cylinder machine would be used. Two of the cylinders would be used for the top and bottom liners and the remainder for the filler and center stock.

To give a cleaner, brighter, well-closed, and better printing surface, two cylinders are frequently used for the outside liner that is to be printed. The inside layer of this double liner may be made by putting news stock onto the cylinder next to that forming the top liner, or side to be printed; this is called a *skim news backing*. The object is usually to cover up the dark or colored spots frequently obtained from chip filler stock, the news being lighter and cleaner, and forming a better 'foundation' for a bright looking liner ply. If three other stocks were used, this would necessitate a four-way system (see under Newsboard, Art. **91**). Combination boards are finished as described under Boxboards, Art. **79**.

Combination chipboards have a *chip* (mixed papers) base or filler, and are vat-lined with higher grades of stock that possess a smoother surface, such as news, sulphite, etc.

Combination manila boards have a 40% unbleached sulphite and 60% groundwood filler, and usually are vat-lined with patent coated furnish; may also be clay coated.

Combination pulpboard (the term is not strictly accurate) usually has a chip filler, with liner or liners of manila clippings, groundwood pulp, unprinted news, etc.

Combination strawboards, now very little used, have straw for the filler and other stocks, such as 'chip vat-lined'; or are vat-lined with groundwood, unprinted newspapers, etc., and called *pulp-lined strawboards.*

The term *vat-lined* simply means the addition of another cylinder ply, of another stock, during formation on the wet end of the board machine. The term may be applied to another ply of the same stock but of different color. *Clay-coated boards* are also included in the term combination boards.

83. Container Board.—A built-up board, consisting of all-kraft or jute liner (the latter usually made of kraft pulp lined with strong waste papers) for the outer plies, and corrugated, mixed papers, or strawboard for the center. The liner requires good color, water resistance, stiffness, strength, and bending qualities. Container boards are often called *test boards.* The finished board is sometimes chip center, double lined with test liner sodium silicate pasted. Used for shipping containers.

RAW MATERIALS: Kraft pulp, waste kraft paper, manila, and newspapers for liner, and screenings, sulphite, and mixed papers for filler; stock used in various proportions, with the stronger fiber predominating in outer plies. A good board is also made of 50% steamed groundwood and 50% kraft, combining the stiffness of the one with the strength of the other.

PREPARATION: Picking out asphalt and tar papers, etc., at the beaters is usually sufficient sorting. Old papers opened up in continuous beater; kraft fiber should be beaten 3 or 4 hours and then mixed. Liner stock is better sized than filler; 1% to 2% rosin should give 3-hr. water resistance, while 3% to 4% should give 24-hr. water resistance, with enough alum in each case to give best results. Liner usually colored buff, orange, brown (standard color), or black; colors may be alkali-proof. Both

filler and liner stock must be well jordaned, preferably using 2 or 3 Jordans in series.

MAKING AND FINISHING: A 6- or 8-cylinder machine is generally used, with 5 to 6 suction boxes on the felts, 2 to 3 wringer rolls, extractor, suction roll or suction drum roll, 7 baby presses, 3 to 4 main presses, including suction press, 100 to 150 36-in. dryers (or the equivalent in larger dryers), 3 stacks of calenders for best finish (2 stacks for lower finish). These boards are made at speeds up to 250 or 400 f.p.m. Usually slit and rewound for shipping rolls.

84. Felt.—This term is applied to a group of papers of soft or absorbent quality; known also as *deadening felt, carpet felt,* and *carpet lining;* used under flooring, carpets, and linoleum, and as dry saturating or roofing felt, to be impregnated with tar, asphalt, etc. Also used as insulation for refrigerators and refrigerator cars. Must be firm, pliable, durable, free from lumps, and with a smooth surface, not too absorbent for linoleum lining that is to be cemented to the floor and to the linoleum.

RAW MATERIALS: Deadening or roofing felt usually contains 50% to 70% roofing rags and 50% to 30% news, mixed paper, or common paper. The better the grade the higher the proportion of rags, the quality of the rags also being a factor. Another furnish for carpet felt is 60% bagging and cotton waste, 35% waste papers, and 5% roofing rags. The rags are the throw-outs from the sorting for finer papers, and are often old, tender, and dirty.

PREPARATION: Non-papermaking junk is sorted out, and the rags and papers are given a preliminary cutting up. Rags and papers should be beaten separately and mixed at the Jordan headbox; the rags are beaten with a sharp tack for 1 hr. to 1½ hr.; no cooking, sizing, coloring, or loading is required.

With the second furnish, the bagging and rags are beaten ½ hr., then the papers are added and the beating is continued an hour. The stock is usually jordaned hard, sometimes with two Jordans in series, but some mills do not jordan at all. The object is to get a very free stock, one that will make a thick, soft sheet on a single cylinder.

MAKING AND FINISHING: A single cylinder, from 36 to 60 in. in diameter, is generally used, though some mills use Fourdriniers. The speed varies from 40 to 125 f.p.m., depending on the weight

of the paper, the consistency at the headbox being 0.5% to 1%. This paper is but lightly calendered, and is slit (usually 36 in. wide) and rewound in 50-yd. rolls, marking the yardage. A 50-yd. roll of ¾-lb. felt weighs 37½ lb.; of 1-lb. felt, 50 lb.; of 1½-lb. felt, 75 lb. A ¾-lb. felt weighs ¾ lb. per sq. yd. Felts are also designated by the weight of 480 pieces 12 × 12 in., or 480 sq. ft. On this basis, ¾ lb. per sq. yd. = 40 lb. per 480 sq. ft.; a 1-lb. felt (per sq. yd.) = 53⅓ lb. per 480 sq. ft.; and a 1½-lb. felt (per sq. yd.) = 80 lb. per 480 sq. ft. The weight per 480 sq. ft. is the basis generally used by the paper mill for dry felts before they are saturated; after saturating, the weight is referred to as pounds per square yard.

85. Fiber Board.[1]—A tough, pliable, water-resistant board, capable of being molded, as for shoe counters and inner soles; used also for suitcases, etc.

RAW MATERIALS: One furnish for this grade contains 80% strings—jute or manila preferred—and 20% fiber-board strips.

PREPARATION: The strings are cooked 12 hr. at 30 lb. pressure, with 7% lime and 3% soda ash. The strings are drained, washed, and then beaten for an hour, when the board cuttings are added, and the whole is beaten a full 12 hr. A wax size is used, with sufficient oxide of iron, or ocher, to give the desired tint. No jordaning.

MAKING AND FINISHING: The board is run on a cylinder wet machine, stripped from the couch roll, and dried either outdoors or in a rack and tray dryer, with steam coils and positive fan circulation. Molded articles are cut and shaped from the wet board, and then dried. A flat board is finished in a 2-roll board calender, trimmed, and tied in bundles. This type of board may also be molded when dry by pressing between heated platens.

Folding Boxboard.—See Boxboard, Art. 79.

86. Friction Board.—A heavy, compressed solid board, used for making friction disks and paper pulleys, by cutting out circles and bolting several of them together. Must be hard, tough, water resistant, non-warping, and with glossy finish.

RAW MATERIALS: Jute strings, manila rope, cotton rags; cooked 16 hr. at 40 lb. pressure, with lime and soda ash; loss in

[1] This type of board is more correctly called *counter board* or *heeling board;* the term fiber board is more generally applied to a vulcanized fiber board.

cooking is 20% to 25%. Stock is drained, loaded into beater with roll set to bedplate; washed until free from alkali; low-grade red oxide of iron is added for color, and stock is brushed out at high consistency for 10 hr. to get maximum hydration. As high as 100% rosin in emulsion is used, with 10% to 15% alum (1.3 sp. gr.) added 1 hr. before dumping; no jordaning; rod mills are also used for beating.

MAKING AND FINISHING: Made on cylinder wet machine by winding up on couch or take-off roll until of required thickness ($\frac{1}{8}$, $\frac{3}{16}$, or $\frac{1}{4}$ in.), and taken off in sheets 38 × 42. The board is pressed in hydraulic press; dried in open air in summer, and in rack dryer (with steam coils and fan draft) in winter; trimmed on edges, and tied in 60-lb. bundles for shipping.

87. Leather Board.—A solid board, made of pulped scrap leather and waste paper, with or without jute. The paper is beaten first, about 7 hr., and chrysoidine is added about 30 min. before dumping. A long, coarse fiber is obtained, which is run off on a wet machine and finished as described under Fiber Board and Friction Board. Used for shoe counters, etc. Also called *heel board* and *imitation leather.*

88. Manila Papers.—True manila papers are characterized by unusual strength, toughness, and pliability, because of the long, strong fibers of the hemp manila and jute plants from which they originally came. These papers are used for wrapping of maximum strength, backing for abrasive papers, for cement and similar bags, envelopes, tags, and for some electrical insulation work. Manila fiber may be beaten until gelatinous, and made into suitcase and trunk board.

RAW MATERIALS: Old rope, in various grades; jute, as bagging, burlap, or jute tares; kraft pulp. Rope is often used alone; also mixed with either jute or kraft or both; rope may be used alone, but jute is usually mixed with other fibers.

PREPARATION: Rope may or may not be bleached, according to kind and color of product. Cooking conditions vary considerably; beating takes 8 to 12 hours; some mills beat different fibers separately, especially where pulp is used. Bag manila is sized with about 1% rosin and 2% alum; wrapping may have twice as much rosin, while some grades have the same amount of rosin and 3% each of sodium silicate and starch. Rope is given a good

brush in the Jordan; bagging, etc., sometimes not jordaned. The stock is fairly slow.

MAKING AND FINISHING: Most of these papers are made on 2- or 5-cylinder machines, running 70 to 200 f.p.m.; stock consistency is 0.3% to 0.5% in the vats, and the suction about 6 to 7 in. Finish varies from 2 nips on one stack of calenders to all nips on two stacks, with water finish on some grades of wrapping and tag. Bag and envelope stock is usually shipped in rolls; sheets are frequently crated. Tag stock is practically a board.

89. Mill Board.—A stiff board, used for book binding; must be hard, flat, and non-warping. The waste papers used are carefully sorted, cooked with steam, brushed out in beater, sized a little, sometimes tinted with black, and finished in a Jordan. The sheet is made on a wet machine, like friction board, and is calendered by passing several times through the board calender.

90. Mill Bristol.—Often called cardboard; used for show cards, business cards, notices and announcements, etc. It is made in a variety of qualities, from a cheap quality composed mostly of waste papers, groundwood, and a little sulphite, up to a very good quality made of 100% bleached sulphite, and possibly rags. The stock requires careful beating, with the addition of size and color, and occasionally a little loading, which may be in the outer layers only. It is made on a Fourdrinier, a cylinder, or a Harper-Fourdrinier and cylinder machine. Some of the best qualities, such as wedding bristols, used for wedding invitations or announcements, visiting cards, etc., are usually made by pasting several sheets together until the desired thickness is attained. The usual size is $22\frac{1}{2} \times 28\frac{1}{3}$, and the weight for a 500-sheet ream runs from 90 to 200 lb.

91. Newsboard.—May be 'combination newsboard,' with chip filler and news liners, or 'solid newsboard' from all newspapers. Used for cheaper boxes, shirt boards for laundries, calendar backs, for making spiral paper-tube goods, etc.; usually not waterproof; close formation, stiffness, and cheapness are general requisites. Much sold as No. 2 card middles for coating raw stock for car sign board and advertising signs, and for such uses as calendar backs.

Board mills are divided into three classes, depending on how many different kinds of stocks are required for use simultaneously

on the machine. *Solid newsboard*, using only old newspapers, uses what is called a *one-way system;* that is, the beaters, beater chests, Jordans, machine chests, and all cylinders on the machine are connected together, since they are all using the same stock. *Combination newsboard*, using chip filler and news liners, uses a *two-way system;* that is, there is a separate beater-chests-Jordans (machine system) system for both the mixed-paper stock (chip) and the newspaper stock; these are generally so arranged that they can be interconnected; hence, a one-way system can be used if desired. A *three-way system* would be necessary when three different kinds of stock were used, as in the case of a *manila-lined chip, news back*. While formerly much newsboard was made in two-, or three-way mills, it is usually a 'production' sheet rather than a 'quality' sheet, as in the case of the folding boxboards to be printed; hence, as the latter class of mills is usually not equipped to make production records, newsboard is now generally made in mills that can turn out large amounts at a low cost.

Raw Materials: Poor grades of news packings, sorted at the beaters; better packings, unsorted. Not now cooked or bleached, as cooking is unnecessary, and the natural gray color of the pulp is good enough for the purpose; 10% sulphite is sometimes used in newsboard (90% newspapers), in order to free up the stock and allow greater production, to strengthen the sheet and thus increase production. Sulphite in the liner also improves bending quality.

Preparation: Either defibered in dropping beaters, where size and alum are added, or in breaker beaters and thence to dropping beaters; the latter is the usual practice. Clay is sometimes used to give better surface and finish; usually not over 1% of rosin size used; alum may be 2% to 3%, if an extra stiff sheet is required. Colored in beater, on calenders, or both. Jordans are well set up, to give closely formed, stiff sheet. Because of shortness of fibers, the stock is rather slow.

Making and Finishing: A 6- to 8-cylinder machine is generally used; but a machine to make only newsboard would need fewer cylinders, 2 to 4, unless very thick calipers or large production were to be required. Since a good printing surface is not necessitated, then, unless colored, the speed can be up to 300 f.p.m., depending on the weight of the sheet. For the low-caliper sheet, a faster speed can be used, depending on the number of cylinder

molds used, because of greater drainage area of wire available and the consequent ability to pick up a light ply on each cylinder; hence, 2 to 4 cylinders will work well for low productions of newsboard, while 6 to 8 cylinders will allow a maximum for ordinary-caliper sheets.

Newsboard is finished the same as for folding boxboard. A water finish may be given if the board is sized sufficiently. It is sometimes pasted on a roll or sheet paster. The board is shipped in rolls or in sheets (50-lb. bundles).

92. Patent Coated Board.—Not clay coated, but faced with a high-grade liner. It occupies a place intermediate between dry coated boxboard (which is the highest priced material commonly used for folding boxes) and various lower grades, such as bleached manila-lined newsboard, white-blank-lined newsboard, etc., which do not give the good appearance of patent coated boards, but are cheaper. It is used for most of the printed folding boxes, display cartons, lithographed products, etc. Requirements include: in liner, good printing surface, resistance to absorption of printing ink, good bending quality, even color, good sizing, no fuzz; in filler and bottom, no lumps, no specks; in whole board, good bonding between liner and filler, uniform thickness, cleanliness, uniform weight. The product may be single or double lined.

Materials: While the raw stock varies somewhat with grade of product and material available, the following may be taken as a representative furnish: the filler and bottom liner are the same, all overissue newspapers (with rotogravure and colored sections thrown out), sorted at the beaters for strings, sticks, etc. The top liner is made on 2 cylinders, and contains 500 lb. of easy-bleaching sulphite, 600 lb. of No. 2 hard white shavings, 500 lb. of No. 1 hard white shavings, 500 lb. of soft white shavings.

Preparation: A few mills de-ink printed waste paper for making liner. In the lower qualities, no real beating is done, liner stock being from $\frac{3}{4}$ hr. to 1 hr. in the beater. The higher grades, in order to secure closer liner formation without fuzz or sacrifice of bending quality by excessive jordaning, may be beaten from 1 hr. to 3 hr. Close formation gives resistance to penetration of printing ink. Filler stock is defibered only, usually in breaker beaters. Filler stock may contain 1% of size, and liner stock, 2%, with alum to a state of slight acidity; also, 3 pails of

starch, 1 gal. of sodium silicate, and 100 lb. of clay (on basis of above furnish), and tinted for white with a little blue; loading is not commonly used. The size reduces fuzz, prevents blackening on the calenders, and keeps water from penetrating during lithographing. Liner stock is colored in the beater, on the calenders, or both; a color may be started in the beater, and developed and finished on the calenders; the filler is not usually colored. The filler is lightly jordaned, the liner to a point of fuzz elimination, since freeness is desired; the thicker the board the less the jordaning.

MAKING AND FINISHING: These operations are about the same as for chipboard; use finer screen plates, finer and closer felts, finer cylinder wires,—60-mesh for liner, 50-mesh for filler,—rolls more accurately ground, slower speeds, and better machine adjustments. For example, liner must have no felt marks; may use dandy roll on liner cylinder; machine speed, 150 to 220 f.p.m., depending on number of cylinders, number of dryers, etc.; machine calendered and water finished; 3 stacks. Cut in sheets; packed in 50-lb. bundles or on skids. Also sheet calendered or plater finished for special surfaces; or may have special surface applications of special preparations in water boxes.

93. Pulpboard.—A true pulpboard would be made of wood pulp,—100% groundwood to 50% groundwood and 50% sulphite. The term is also applied, however, to boards containing paper stock, and may be combined or solid boards. Used for setup (non-folding) boxes; cracker, can, and box layers; circles for packing fruit in barrels, etc.; bottle-cap board (waterproofed) for milk-bottle caps. A grade of solid wood-pulp board, free from mineral, is used in batteries. *Pulp lined strawboard*, sometimes called *straw-pulpboard*, is made in fair amounts, and consists of a straw center, or filler, with liners of groundwood, white blanks, etc.

RAW MATERIALS: New groundwood pulp, blank newspapers, mixed papers, news, straw, and bottle-cap clippings, in various proportions; the use of sulphite pulp raises the grade, giving bending qualities, but this product is not commonly considered as pulpboard. A small amount of strong fiber, such as sulphite pulp, manila cuttings, bottle-cap clippings, etc., is necessary for proper handling on the machine.

PREPARATION: No actual beating required; stock is well defibered, using hot water on sized clippings. Up to 4% size is used for waterproof board for bottle caps; solid wood-pulp board is sized as required by order, adding alum to acidity. These boards are sometimes loaded with clay, to give a whiter and smoother sheet. The stock is moderately free, and is fairly well jordaned. The outside layer (liner) is sometimes tinted with violet.

MAKING AND FINISHING: A 5- to 8-cylinder machine is generally used, sometimes without top felts. The vat circle[1] is usually larger than in the case of folding boxboards. There are usually extractor rolls, suction or suction drum roll, baby presses, suction presses, and 3 main press rolls, including suction press. Two calender stacks are generally used, except for No. 4 finish, which requires 3 stacks. This board is frequently built up of layers, pasted on a roll paster. Pulpboard is generally packed in 50-lb. bundles, whatever the size of the sheet; it is sometimes shipped in jumbo rolls.

94. Strawboard.—A term referring to a kind of cheap, coarse board, made on a multicylinder machine from incompletely cooked straw; may be combination or solid. *Combination strawboard* is a board having a straw base or center, and is lined on one or both sides with a higher grade of stock, possessing a smoother surface. *Solid strawboard* is a board made entirely from straw pulp. *Straw wrapping* is little used now, comparatively, but large quantities of strawboard are used. The usual thickness for corrugating is 0.009 in.; it is softened slightly for the corrugating machine, which dries it. The crowns of the corrugations are touched with sodium silicate adhesive, and a liner is applied to one or both sides. Light weight, stiffness, and smooth finish are desired.

RAW MATERIALS: Wheat and rye straw are preferred; oat straw has a shorter fiber.

PREPARATION: Straw is cooked in rotary boilers, a charge consisting of 6 to 6½ tons of dry straw, from 1200 lb. to 1700 lb. of lime (slaked), according to calcium content, using about 4 gal.

[1] By *vat circle* is meant the radial distance from the woven-wire screen on the cylinder mold to the inside of the vat proper; this distance varies from about 3 in. to 7 in. The smaller this distance the more compact the formation of the sheet, but the less the production, because of slower drying. In general, the larger vat circles are used for wood-pulp boards, from 5 in. up, because of the more open sheet formed.

of water per 10 lb. of straw. The straw is charged in about 6 'fills,' with about 20 min. at 25 lb. pressure (wilting) between fills. Cooking takes about 10 hr. at 40 lb. to 45 lb. steam pressure. Gassing down (relieving steam pressure after cooking) takes 15 min. to 30 min., and dumping, from 1 hr. to 3 hr. Straw from the rotaries is broken up in breaker beaters, washing simultaneously; then it is beaten 2 hr. or 3 hr., drawing fibers out gradually, washing meanwhile about 2 hr. to get the straw practically free from lime. No size, loading, or color is used. The stock is put through 3 Jordans in series and set up tight, and usually goes into the machine without screening.

MAKING AND FINISHING: Although strawboard is produced on several Fourdrinier machines, the custom is to use a single-vat cylinder machine, with soft-rubber couch roll, suction box on the wet felt before couch roll, squeeze roll, suction 'tail' or pull roll, suction first press, and second press. A suction box is used on second-press felt to keep free of lime; smoothing rolls are helpful. Speeds are 150 to 325 f.p.m. Cylinder molds 4 ft. to 6 ft. in diameter have been used.

A smooth finish is obtained with 2 calender stacks; or 1 stack with 2 steam-heated rolls or a steam shower. Strawboard is reeled, slit, and rewound, or shipped in jumbo rolls. In many places, it can be trucked direct from the mill to the corrugating and box plant; or it is shipped in carloads.

95. Wallboard.—This name is applied to a group also known as *building boards;* used in place of lath and plaster for finishing the interior of houses, and for other purposes where its character makes it useful, as for advertising displays, booths, jig-saw puzzles, etc. Characteristics required are: rigidity, non-warping from atmospheric moisture, light weight, adhesion of separate plies, good painting surface. Usually shipped 12% moisture to damp climates and 10% to dryer locations, to compensate for atmospheric moisture and to reduce possibility of warping. There are several varieties of building board, and that generally known as wallboard will be described first.

The terms wallboard, pulpboard, building board, plaster board, and gypsum board have all been much misused and misunderstood. The trade today recognizes three distinct names; *viz.*, wallboard, gypsum board, and plaster board.

Wallboard is a 3- or 4-ply board, built up by laminating or pasting 3 or 4 plies of heavy paper or board, using sodium silicate as an adhesive. The several plies may be made of any low-price pulp and old paper; the outside surface is treated to make it water resisting, and the product is used in place of lath and plaster, as mentioned previously.

Gypsum board is made by rolling plaster of Paris (while still plastic) between two sheets of a specialty-combination paperboard, and when the plaster of Paris has set, it binds the whole together in a finished product sometimes decorated before distribution.

Plaster board and *lath board* are a medium sized, lighter weight wallboards with gypsum center, made for use as a substitute for wood laths; it is covered with the regular wall plaster.

In addition to the 3- or 4-ply wallboards, there are several solid boards on the market, made in special hydraulic presses, followed by drying in dry kilns.

Raw Materials: These vary with different boards, but they include groundwood pulp, groundwood screenings, unbleached sulphite, sulphite screenings, mixed papers, bagasse, lumber waste, etc.

Preparation: Treatment depends on the material; a typical wood-fiber wallboard is built up by pasting 2 center plies and 2 outer plies, the former containing 15% to 25% groundwood screenings and 85% to 75% groundwood pulp, ground without barking the wood; the outer layers consist of 15% to 25% of groundwood screenings and 85% to 75% of clean groundwood. The pulp is defibered in pulping engines or beaters, along with broke and finishing-plant waste (silicated). The center will have 3% rosin and the liners 4%, with enough alum for acidity, though some mills use only 1% rosin. Jordaning is fairly heavy. The liner stock must not be slower than filler stock, on account of 'blowing.'

Making and Finishing: Center and liner boards are 0.046 in. thick; made on a cylinder machine having 6 or 7 vats, with regular squeeze rolls, presses, felt suction boxes, etc.; speed, 150 to 250 f.p.m.; 1 7-roll or 2 6-roll calender stacks are used. The board is reeled, slit to size, and rewound in rolls, which are shipped to the finishing plant, where they are laminated to finished wallboard by sticking 2 center and 2 liner plies with sodium silicate

adhesive (sometimes with inert material added); they are then cut to wallboard panel size, surface sized by applying rosin in solution with rolls, and dried in a roller dryer (Coe type).

Other Varieties

Several firms are now making insulating boards having special heat-insulating qualities. The same stock is used throughout the board, consisting of such materials as corn stalks, bagasse, licorice root, lumber waste, groundwood screenings, etc., the prepared fiber being free and long. Insulating boards are thicker, stiffer, and more open in structure than ordinary, or inside, wallboard; and, being designed for exterior use, they are heavily sized.

Some board is made by molding the fiber in panels under hydraulic pressure, by a patented process: the greater part is made as a web. The earlier machines are of special 2-cylinder construction, since the ordinary multicylinder machine cannot produce board of the required thickness, usually, $\frac{9}{16}$ in. Continuous vacuum drum filters are now in successful operation on these products. The high vacuum, large area under formation, and dryness of delivered sheet (20% to 25% air dry) result in greater productive capacity and economy. Since the formation occurs in one cylinder only, the possibility of split bond is eliminated, the sheet being homogeneous in composition. The wet sheet is then pressed through presses, either 3 of the standard type or presses of special design, entering the dryers, of the roller or rack type, at about 45% air dry. Top and bottom press felts are used. When the roller (Coe) type of dryer is used, the sheet may be passed through as a web, being cut to panels by two saws at the dry end; or it may be cut to length before entering the dryer, a slitter saw cutting the dried board to proper width. For cutting the wet sheet, a rapidly rotating cutting disk is used, the connected motor and disk (for cutting to length) traveling across the width of the sheet in such a manner that the travel of the sheet is compensated to give a squared cut.

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